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An Implementation Plan for Suspended Particulate Matter in the Phoenix Area
Volume II. Emission Inventory

TRW Environmental Engineering Div, Redondo Beach, Calif

Prepared for

Environmental Protection Agency, Research Triangle Park, N C Office of Air Quality Planning and Standards

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December 1977

AN IMPLEMENTATION PLAN FOR SUSPENDED PARTICULATE MATTER IN THE PHOENIX AREA
VOLUME II - EMISSION INVENTORY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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AN IMPLEMENTATION PLAN FOR SUSPENDED PARTICULATE MATTER IN THE PHOENIX AREA
VOLUME II - EMISSION INVENTORY

by

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1.0 INTRODUCTION AND SUMMARY

This report is the second of four documents associated with a project to develop an air pollution control strategy for total suspended particulate matter in the Phoenix area. The other documents include a review and analysis of air quality data (Volume I), development of the relationship between emissions and air quality (Volume III), and control strategy formulation (Volume IV). The present report (Volume II) presents an evaluation of particulate source emissions throughout the Phoenix area, including a detailed explanation of methodology employed to derive the baseyear and projected baseline emission estimates. The estimates are conducted for three major particulate emission source categories: conventional sources, anthropogenic fugitive dust emissions, and wind blown fugitive dust emissions.

Sections 2,3 and 4 involve the estimation of baseyear emission levels for each of the three major source categories. Each of these sections is organized to provide: 1) a review of relevant previous inventories and other related information, 2) documentation of the emissions estimation procedures adopted for the present study, and 3)the baseyear emissions estimates. The procedures for resolving emissions both spatially and seasonally are developed, and particle size distributions for the various subcategory sources are formulated.

Section 5 concerns the projection of baseline emissions for the year 1980 and 1985. Source growth, activity, and modifications are evaluated, and baseyear emissions adjusted accordingly to forecast future emission levels. In addition, the probable future location of new sources or redistribution of existing source types is examined, and unique spatial source allocations are developed for 1980 and 1985.

A unique feature of the inventory presented here is the preparation of grid maps and graphical emission maps indicating the geographic distribution of the various source emissions. The maps are pertinent to the locational aspects of control strategy formulation.

1.1 RESULTS

Table 1-1 presents the total particulate emissions inventory estimated for the Phoenix study area. In 1975, 54% of the total annual particulate emissions originate from motor vehicles driving on unpaved roads. Another 40% of the yearly emissions arise from four other source categories: construction, dust on paved streets, undisturbed desert, and disturbed soil surfaces. The conventional sources are relatively insignificant in terms of overall magnitude. By 1985, the domination of the emissions inventory by motor vehicle activity on unpaved roads is even more pronounced. In 1985, about 63% of all particulate emissions are expected to be caused by this source.

The wind blown fugitive sources exhibit significant seasonal variations, especially in the baseyear. Unusual meteorology, characterized by low rainfall and relatively high wind velocities, caused greater wind erosion during 1975 than would normally be expected for typical historical meteorology patterns. The forecasted emissions from wind erosion in 1980 and 1985 are substantially lower, due mainly to the assumption that average historical meteorology will prevail in these years. At the same time that wind blown dust emissions may be diminishing, anthropogenic source emissions will be increasing due to population growth and associated increased source activities. The tradeoff of emissions growth and decline between these two major source categories is shown in Figure 1-1.

Figures 1-2, 1-3, and 1-4 provide a graphical display of the distribution of total particulate emissions in 1975, 1980 and 1985. The distribution is dominated by fugitive dust emissions originating from motor vehicles on unpaved roads. While unpaved roads are expected to diminish in number by 1985, especially near the growth belts around the city, the average daily

TABLE 1-1. TOTAL PARTICULATE EMISSION INVENTORY FOR PHOENIX STUDY AREA (TONS/DAY)

	1975					1980	1985				
SOURCE CATEGORY	1st QUARTER	2nd QUARTER	3rd QUARTER	4th QUARTER	ANNUAL AVERAGE	ANNUAL AVERAGE	1st QUARTER	2nd QUARTER	3rd QUARTER	4th QUARTER	ANNUAL AVERAGE
Stationary Sources	22	22	22	22	22	27	31	31	31	31	31
Area Sources	1.4	1.4	1.4	1.4	1.4	1.8	2.1	2.1	2.1	2.1	2.1
Mobile Sources	11	11	11	11	11	13	17	17	17	17	17
Aircraft	.4	.4	.4	.4	.4	.4	.5	.5	.5	.5	.5
Agricultural Tilling	22	30	1	17	20	19	21	29	1	16	19
Vehicles on Unpaved roads	1281	1365	1365	1086	1281	1454	1500	1636	1483	1553	1553
Aggregate Piles	.10	.10	0.10	.10	.10	0.1	.10	.10	0.1	.10	.10
Cattle Feed Lots	6	6	6	6	6	8	8	8	8	8	8
Off-Road Vehicles	71	71	71	71	71	91	107	107	107	107	107
Construction	100	100	100	100	100	254	256	256	256	256	256
Paved Streets	248	248	248	248	248	295	322	322	322	322	322
Wind Blown Agriculture	4.1	4.0	3.8	4.0	4.0	1.7	1.7	1.7	1.6	1.7	1.7
Wind Blown Unpaved Roads	1.4	2.1	2.7	3.8	2.5	.6	.3	.5	.7	.9	.6
Wind Blown Undisturbed Desert	160	244	321	450	294	85	66	112	104	56	85
Windblown Disturbed Soil	161	248	323	456	297	114	43	77	70	39	58
Tailing Piles	1.4	1.4	1.4	1.4	1.4	1.9	2.3	2.3	2.3	2.3	2.3
TOTAL	2091	2354	2478	2478	2360	2367	2378	2602	2406	2413	2462

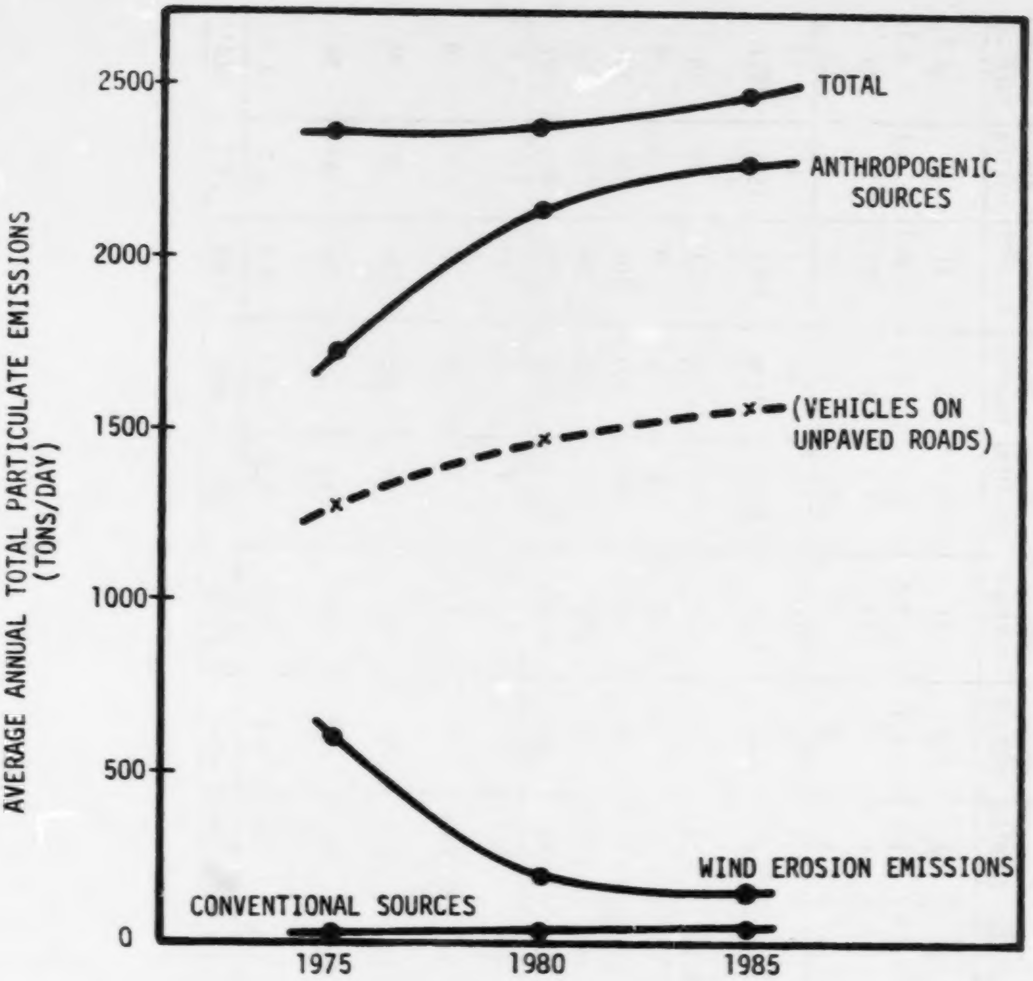


Figure 1-1. Changing Pattern of Major Source Emission Contributions

vehicle traffic is expected to increase substantially, trading off emission reduction benefits from scheduled street improvements. The distribution of emissions around Phoenix shows concentration in the central urban area, as substantial levels of fugitive emissions originate there. Immediately surrounding Phoenix, dust from motor vehicles on unpaved roads are predominant. Inside the urban area, suspension of street dust, dust from construction activities, and emissions from wind erosion of vacant lots and residence yards contribute greatly to city emissions. These distributions remain relatively the same throughout the ten year projection period, although the magnitude of the respective sources changes dramatically for the major subsource categories.

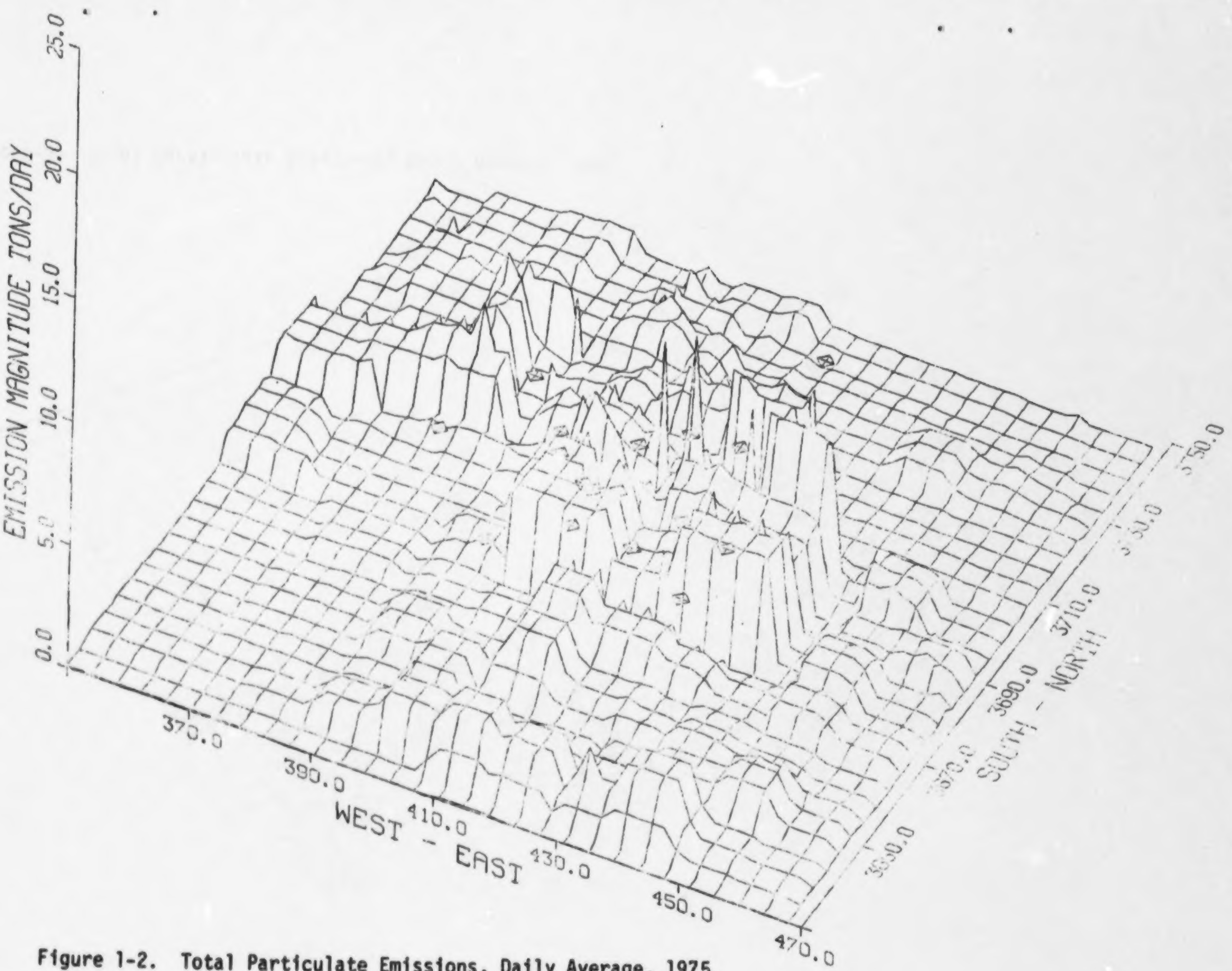


Figure 1-2. Total Particulate Emissions, Daily Average, 1925.

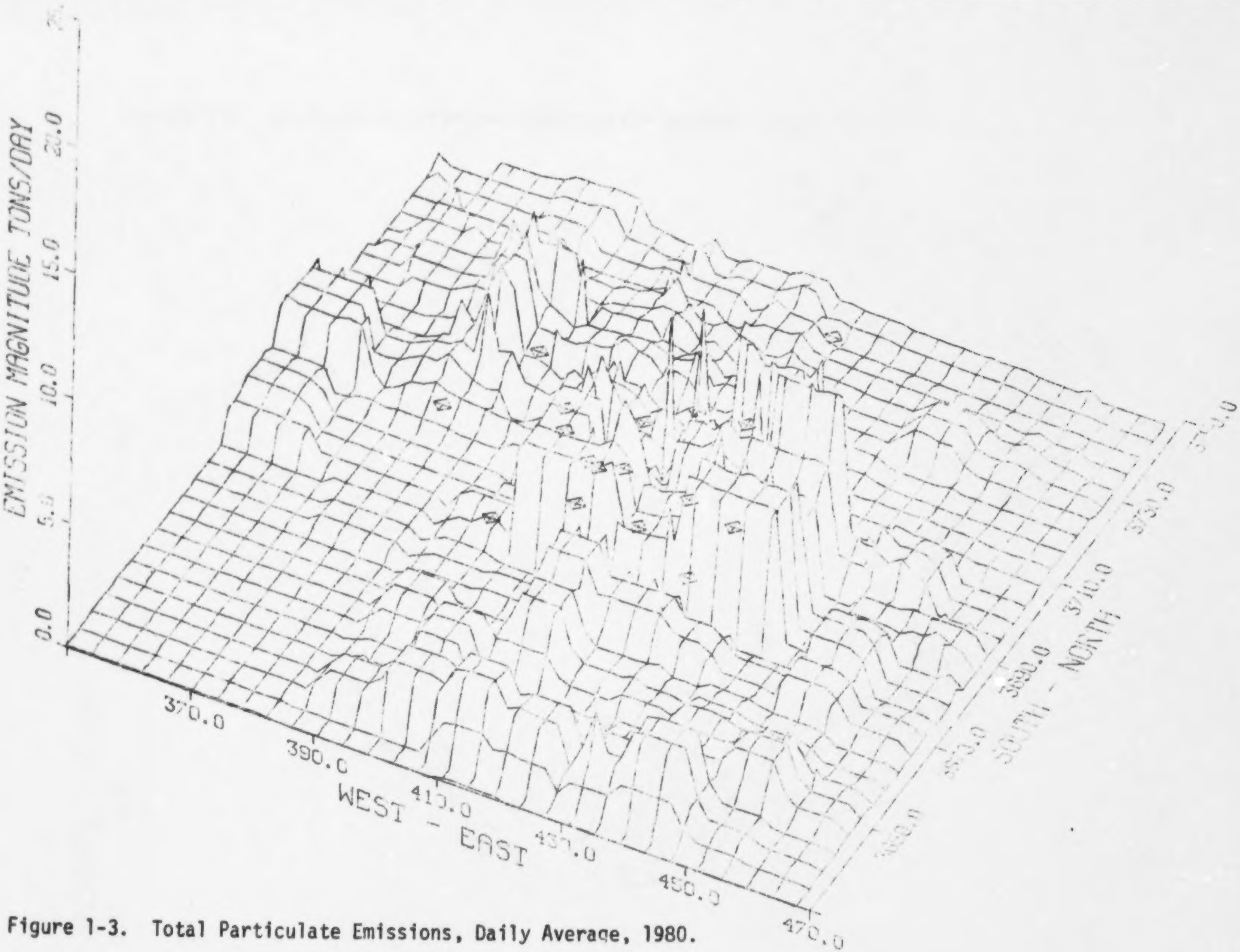


Figure 1-3. Total Particulate Emissions, Daily Average, 1980.

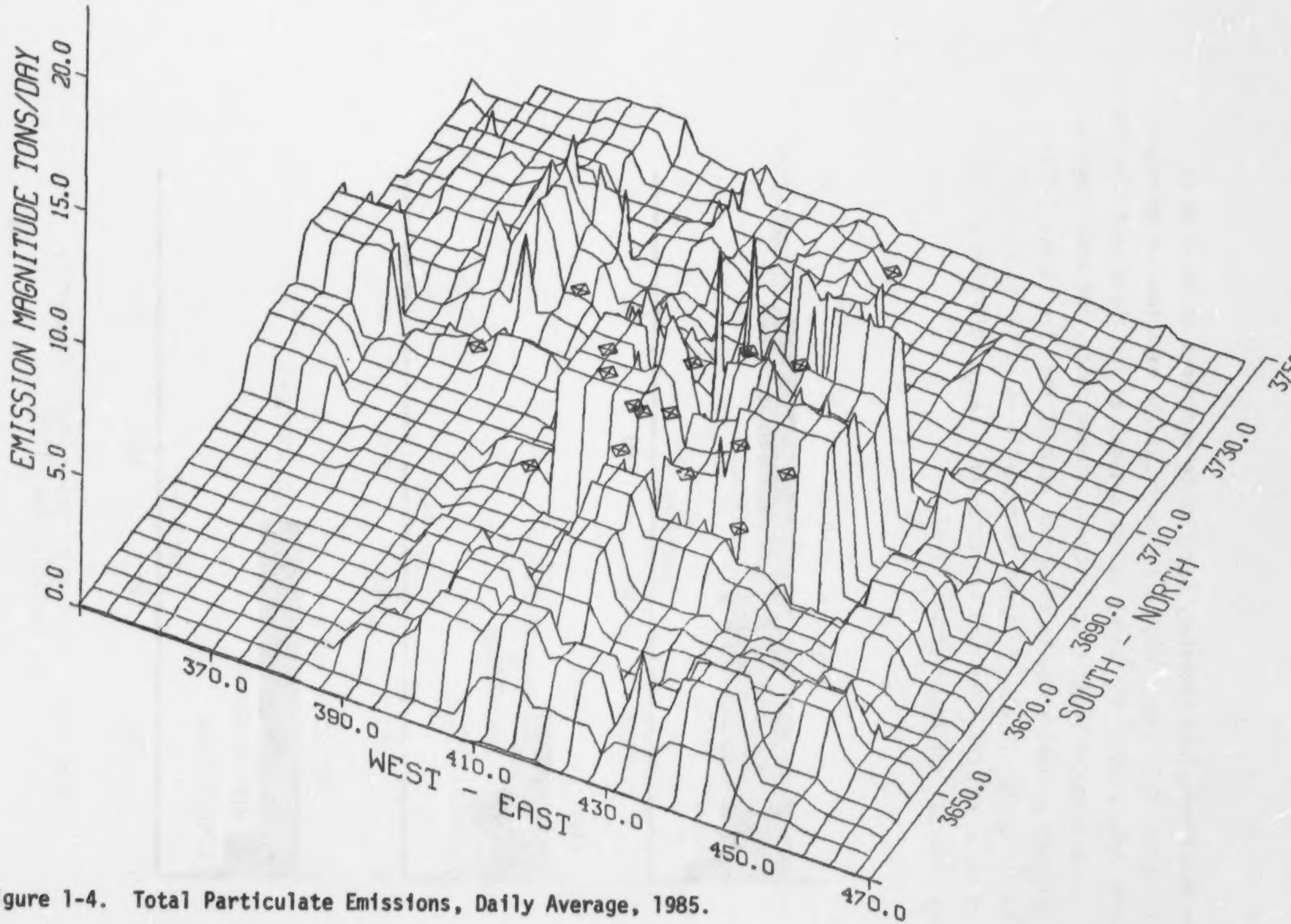


Figure 1-4. Total Particulate Emissions, Daily Average, 1985.

The total emissions inventory may also be expressed in terms of an inventory by particle size. Figure 1-5 portrays the magnitude of emissions originating from each of the major source categories for three particle size ranges. Due to motor vehicle activity on unpaved roads, the anthropogenic source category dominates the inventory in each of the size ranges. This source exhibits high levels of larger size particles as the mechanical action of motor vehicle tires and air turbulence cause injection of soil particles several feet above ground level.

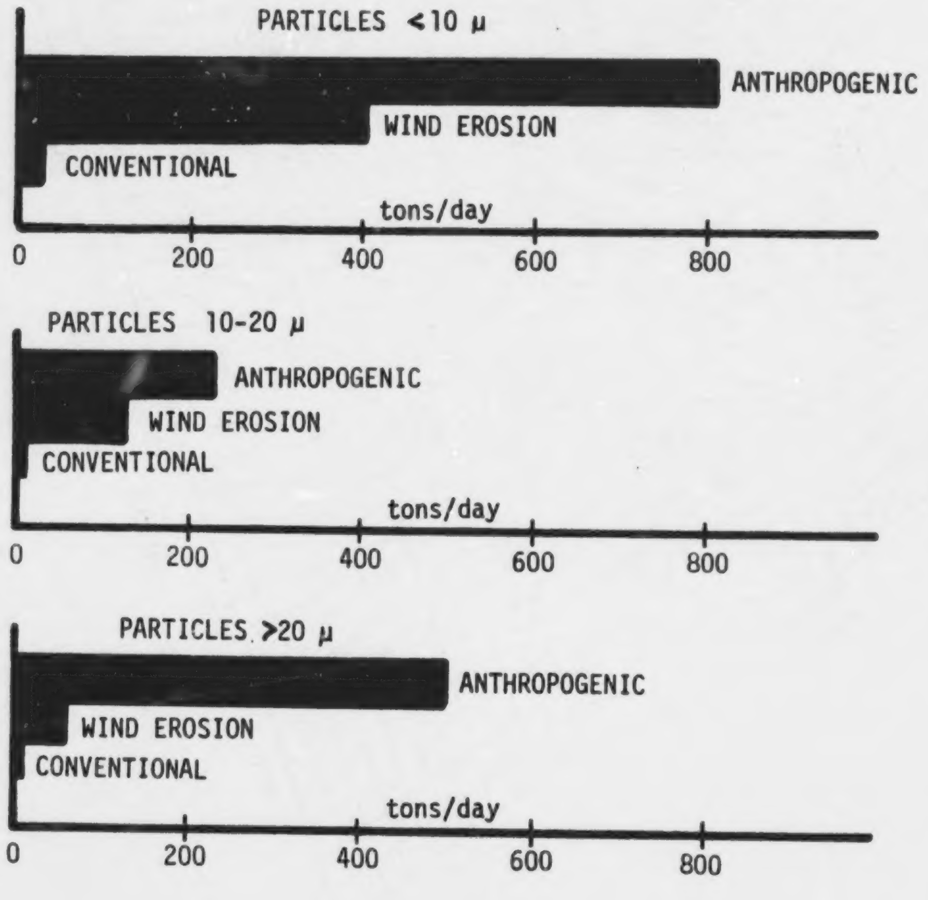


Figure 1-5. Emissions of Major Source Categories by Particle Size, 1975.

1.2 CONCLUSIONS AND RECOMMENDATIONS

- Fugitive dust emission sources are widespread throughout the study area. Virtually all areas in metropolitan Phoenix are in the influence of local sources, and many areas (including monitor sites) are in the plume of local sources (this finding is also supported by recent findings of the IITRI experiment [1]. Control strategies to improve air quality at the various monitor sites must address site-specific source impact as well as regional source impacts.

- Seasonal variations in the Phoenix climate permit fugitive dust emissions generated by wind erosion to attain levels approaching that caused by anthropogenic fugitive dust sources. These wind induced emissions are particularly dense in areas bordering and slightly inside the city of Phoenix, and depending on seasonal meteorology, may affect city ambient levels of total particulates to an extent comparable to that of anthropogenic fugitive dust sources.

- Particulate emissions will continue to increase in future years. This is due primarily to marked increases expected to occur in anthropogenic source activity (vehicle traffic and construction). However, it appears that as development proceeds in the Phoenix area, the rate of increase of emission levels will diminish.

- There are considerable uncertainties associated with the estimation of the baseyear and projected baseline emissions inventories. Fugitive dust emissions are related to may variables and the relationships are not completely understood. The emission estimates compiled here should be regarded as tentative, and should be revised as more comprehensive data become available.

- Additional region-specific field studies are necessary as prerequisites to maximum utilization of existing state of the art emissions estimation procedures. Specific soil characteristics of various sources should be analyzed to provide suitable parametrizations of the various fugitive dust estimation models.

- Additional research should be performed to establish the mechanism of soil suspension under various influence conditions and for different soil characteristics. Empirical and theoretical models are needed to express flux as a real time function of the influence parameters.

2.0 ESTIMATION OF CONVENTIONAL SOURCE EMISSIONS

While reviewing the previous work in the Phoenix area it appeared that fugitive dust emissions would be the major component of any particulate emissions inventory there [1]. It was, therefore, decided that conventional sources would be considered carefully, but without the same level of effort as would be given to fugitive dust emissions. The results shown here support that decision; conventional sources make a relatively small contribution to the regional emissions. However, their inclusion here is important as a number of the point sources and the downtown traffic are very close to monitor sites. Even though their emissions are small, the impact on the local air quality may be significant.

The conventional sources were divided into four categories: motor vehicles, point sources, stationary area sources, and aircraft. The approach to each category was different, primarily because of the differences in their respective data bases. Each category is discussed individually in the sections below.

Both fugitive dust and conventional emissions are organized and spatially disaggregated by use of the TRW Emissions Simulator, a computer program designed to facilitate regional emissions inventories. A grid system is defined with Universal Transverse Mercator coordinates (UTM) by an origin in the southwest corner of the study region and the basic grid square size ranging from 0.5 to 10 kilometers on a side. Each emissions category is then considered individually and resultant emissions are tabulated into their originating grid square. One output file from the Emissions Simulator is compatible with the input requirements to the Climatological Dispersion Air Quality Model (CDM). Point and area sources are kept separate on the CDM input file as required.

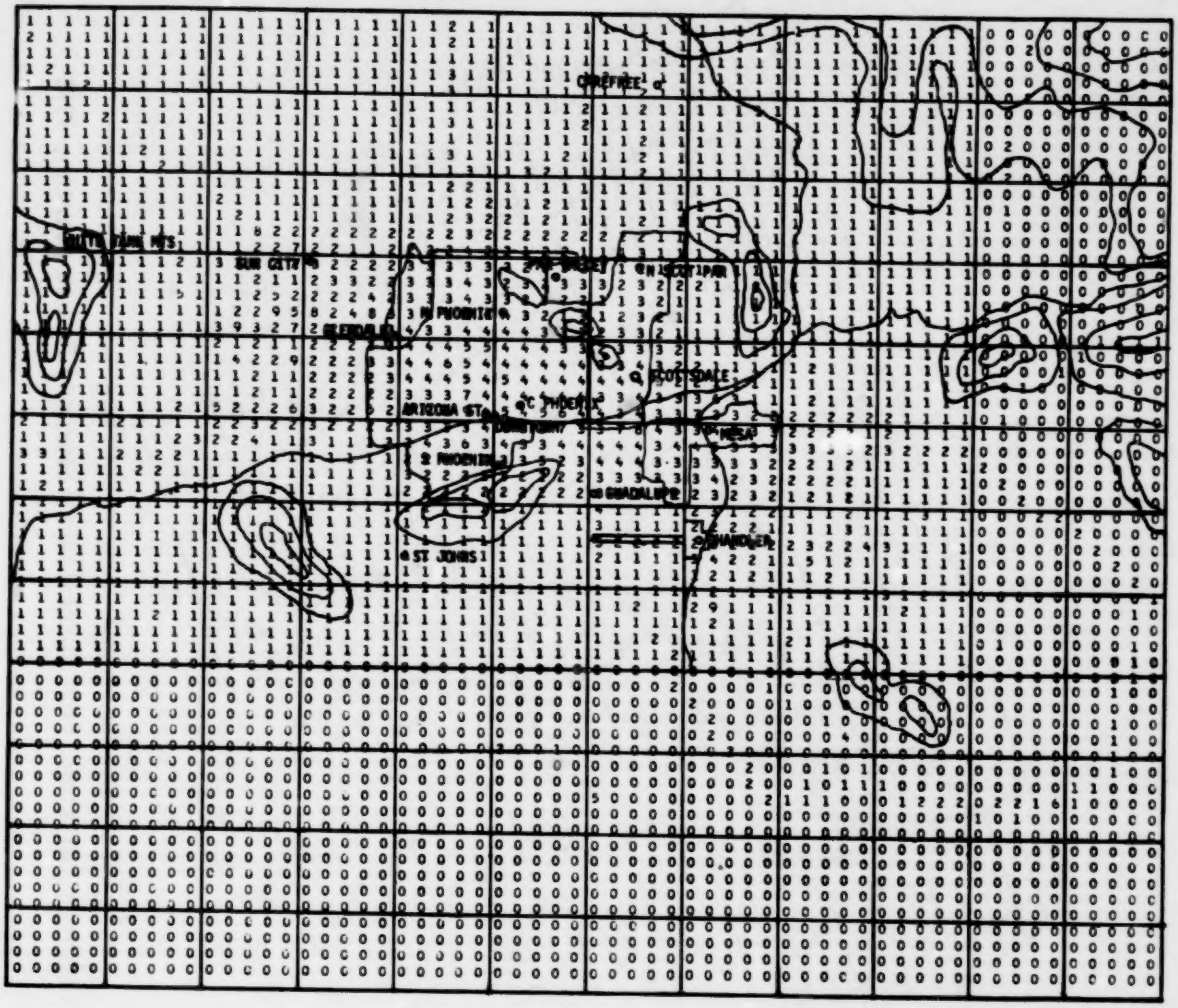
The grid network was defined so as to include a large portion of Maricopa County and the northern portion of Pinal County. This definition allows consideration of all sources which might significantly affect air quality in the heavily populated areas of Maricopa County (i.e., Phoenix area).

The study area is defined as the rectangle with UTM coordinates (zone 12) of the corners as follows: 1) SW corner- 350,000m E., 3,630,000m N., 2) NW corner - 350,000m E., 3,750m N., 3) NE corner- 470,000m E., 3,750,000m N., 4) SE corner- 470,000m E., 3,630,000m N. Each grid square is 2 kilometers (about 1.2 miles) on a side, and is defined by the UTM coordinates of its southwest corner.

Two forms of output are produced by the Emissions Simulator. The first is a printer generated map of the study area with each grid square represented by a number from 0 to 9. An overlay is used with the map to locate important landmarks. A grid legend is included for each map to give the emissions range associated with each grid number. Figure 2-1 is an example of an emissions grid for the total conventional source inventory. On this map a grid square represented by a 4 would indicate between .04341 and .10597 tons/day of particulates are emitted from sources located in that grid square. Similarly, for any grid square on any of the emissions maps, one can find the emission range by comparing the number representing the grid square to that number in the grid legend.

The second form of output generated by the Emissions Simulator is a three-dimensional presentation of the study area emissions. This form is presented in Figure 2-2 for the total conventional source inventory. The scales on the axes are UTM coordinates and tons/day (z axis). The main purpose of this output is to permit a quick and concise perspective of the spatial distribution of emissions from any source category. The"Emissions Magnitude" scale is automatically self-scaling to provide spatial resolution of even the less significant source categories such as airports. The air quality monitor sites are depicted with symbols as shown.

A summary of baseyear conventional source emissions is presented in Table 2-1. The total magnitude of the conventional source emissions is relatively insignificant for a region as large as the specified study area. This is consistent with expectations and previous studies of the Phoenix area. Point sources and motor vehicles contribute about 95% of the conventional inventory emissions. These sources are most heavily concentrated in the urban and urbanization expansion areas of the study region as shown by the grid map of Figure 2-1 and the emissions graphics of Figure 2-2.


CAREFREE
WHITE TANK MTS
SUN CITY
GLENDALE
N PHOENIX
N SCOTTIPAR
SCOTTSDALE
ARIZONA ST
C PHOENIX
DOWNTOWN
S PHOENIX
MESA
GUADALUPE
CHANDLER
ST JOHNS

```
                GRID LEGEND


      GRID              EMISSIONS
      CODE              TONS/DAY


       C      0.00000 TO    .00000
       1       .00000 TO    .00271
       2       .00271 TO    .01373
       3       .01373 TO    .04341
       4       .04341 TO    .10597
       5       .10597 TO    .21975
       6       .21975 TO    .40711
       7       .40711 TO    .69452
       8       .69452 TO   1.11248
       9      1.11248 TO   1.69560
```

Figure 2-1. Emissions Grid Map for Total Conventional Sources Inventory, 1975.

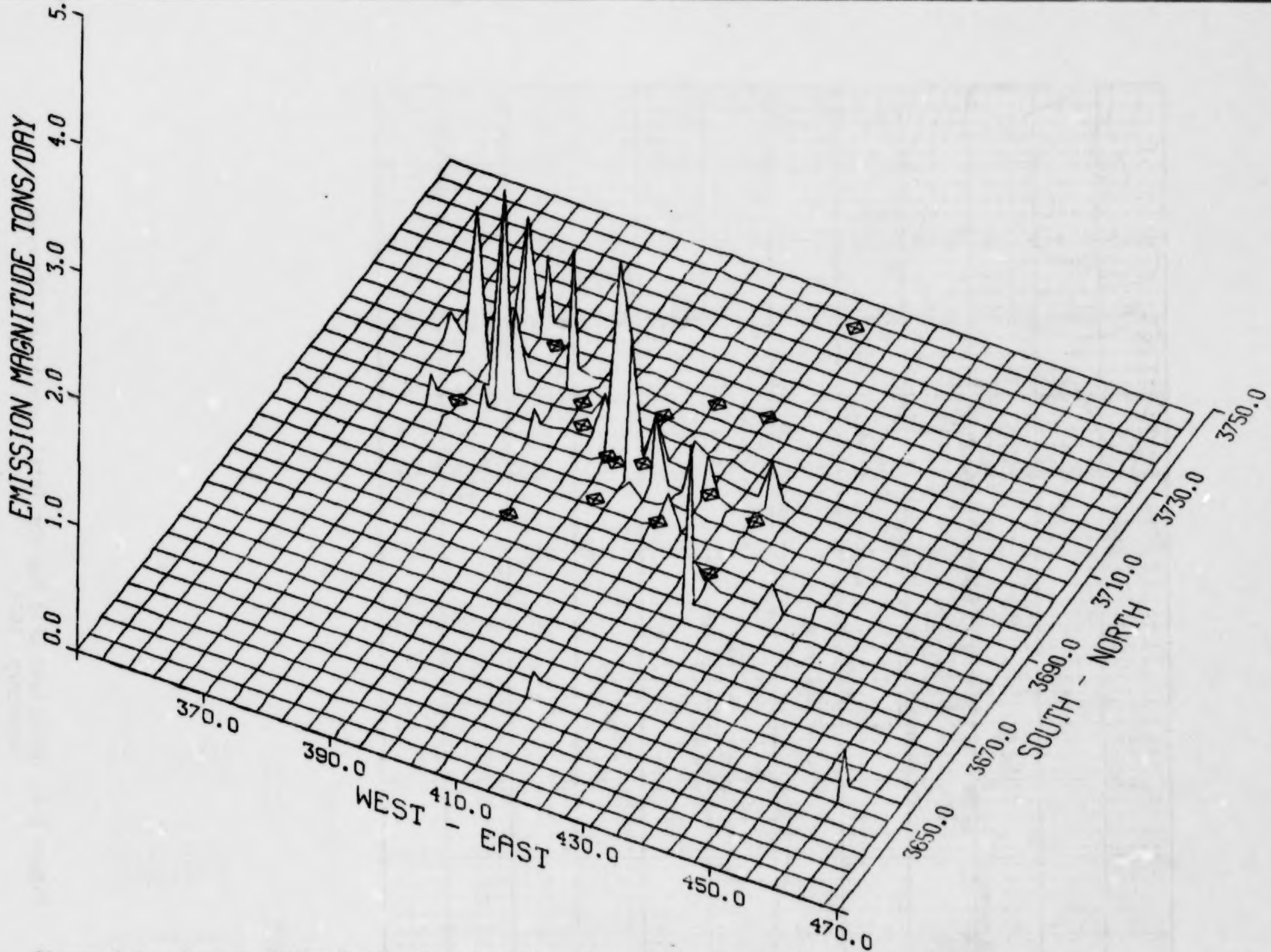


Figure 2-2. Average Daily Particulate Emissions from Conventional Sources, Fourth Quarter, 1975

TABLE 2-1. SUMMARY OF BASEYEAR CONVENTIONAL SOURCE EMISSIONS

CATEGORY	TONS/DAY
Point Sources	21.8
Stationary Area Source	1.4
Aircraft	0.4
Traffic	11.0

2.1 MOTOR VEHICLES

2.1.1 Review of Previous Inventories

The only previous inventory reviewed was that of PEDCo [1]. In that study the motor vehicle emissions were included with other area sources from NEDS. The method used by NEDS is to multiply the number of gallons of gasoline sold in the county by an emission factor to obtain the county traffic emissions.

One obvious limitation of the PEDCo inventory is that this information is outdated. The latest available NEDS data was for 1972 at the time of this study. Since that time many changes have taken place in the automotive industry including increases in gasoline mileage and decreases in emissions per vehicle. Another possible limitation concerned the potential of the grid system to provide suitable spatial resolution of sources. The minimum grid square was 10 kilometers, which does not permit disaggregation of emissions to the extent that localized emission levels may be represented. The degree of spatial resolution attained by the emissions grid network is related to the ability of the air quality model to predict receptor concentrations in agreement with observed air quality measurements.

2.1.2 Methodology of the Present Inventory

A computer tape containing the 1975 Historical Record and Link Data from Maricopa County was obtained from the Arizona Department of Transportation [2]. The tape included the coordinates and volumes of all paved roads (excepting some residential streets) in the metropolitan area so that VMT (vehicle miles traveled) could be calculated for each grid square. Emissions from each link were assigned to grid squares proportional to the fraction of the link lying in a given grid square. For example, if half of a link lay in a given grid square, then half of its emissions were assigned to that grid square.

Total VMT was found to be 16.7 million miles per day in 1975. This figure for VMT includes some 1.4 million miles per day which were added to the data received from Maricopa County. These extra vehicle miles traveled include highway and freeways in the outlying portions of Maricopa County and Northern Pinal County which were not included in the County Historical Record. A publication from the Arizona Department of Transportation provided the necessary information [3].

County registration data from 1975 was used to distribute the total VMT to the various vehicle classes [4]. The distribution of VMT was assumed proportional to registration data and is given in Table 2-2 Since the heavy duty vehicle (HDV) class was not registered by the subcategories of gasoline and diesel, it was assumed that half of HDV's were gasoline and half diesel.

TABLE 2-2

VEHICLE DISTRIBUTION
(FRACTION OF TOTAL VEHICLES)

LDV	.731
LDT	.099
HDV Gas	.060
HDV Diesel	.060
Motorcycle	.049

All emission factors were produced in accordance with Supplement No. 5 of AP 42 [5]. The Fraction of Miles by vehicle age group from light duty vehicles (LDV) and light duty trucks (LDT) classes are assumed equal to the national averages. Tables 2-3 and 2-4 show the calculations used for LDV and LDT emission factors.

Heavy duty gasoline and diesel vehicles were assumed to have an average of six tires (for purposes of tire wear estimates). Exhaust and tire wear emission factors for HDV and motorcycles are calculated below. Motorcycles were assumed to be 40% 2-stroke in accordance with national figures.

HDV Gasoline

$$E_o = .91 + .20\ (6/4) = 1.21 \text{ gm/mile}$$

HDV Diesel

$$E_o = 1.30 + .20\ (6/4) = 1.60 \text{ gm/mile}$$

Motorcycles

$$E_o = .40\ (.33) + .60\ (.046) = .160 \text{ gm/mile}$$

The emission factors for the five vehicle classes were combined via the Vehicle Distribution from Table 2-3 as follows:

$$E_o = .731\ (E_{LDV}) + .099\ (E_{LDT}) + .06\ (E_{HDV\ gas}) + .06\ (E_{HDV\ diesel}) + .049\ (E_{mc})$$

$$E_{1975} = .731\ (.51) + .099\ (.52) + .06\ (1.21) + .06\ (1.60) + .049\ (.16) = .601 \text{ gm/mile}$$

2.1.3 Emission Estimates

Using the procedure outlined in Section 2.1.2, motor vehicle emissions were computed. The 1975 motor vehicle emissions were 10.2 tons/day. Shown in Figures 2-3 and 2-4 are the graphical representations of emissions from traffic over paved roads (Refer to Section 2.0 for an explanation of these graphics.).

TABLE 2-3. LIGHT DUTY VEHICLE EMISSION FACTORS (gm/mi)

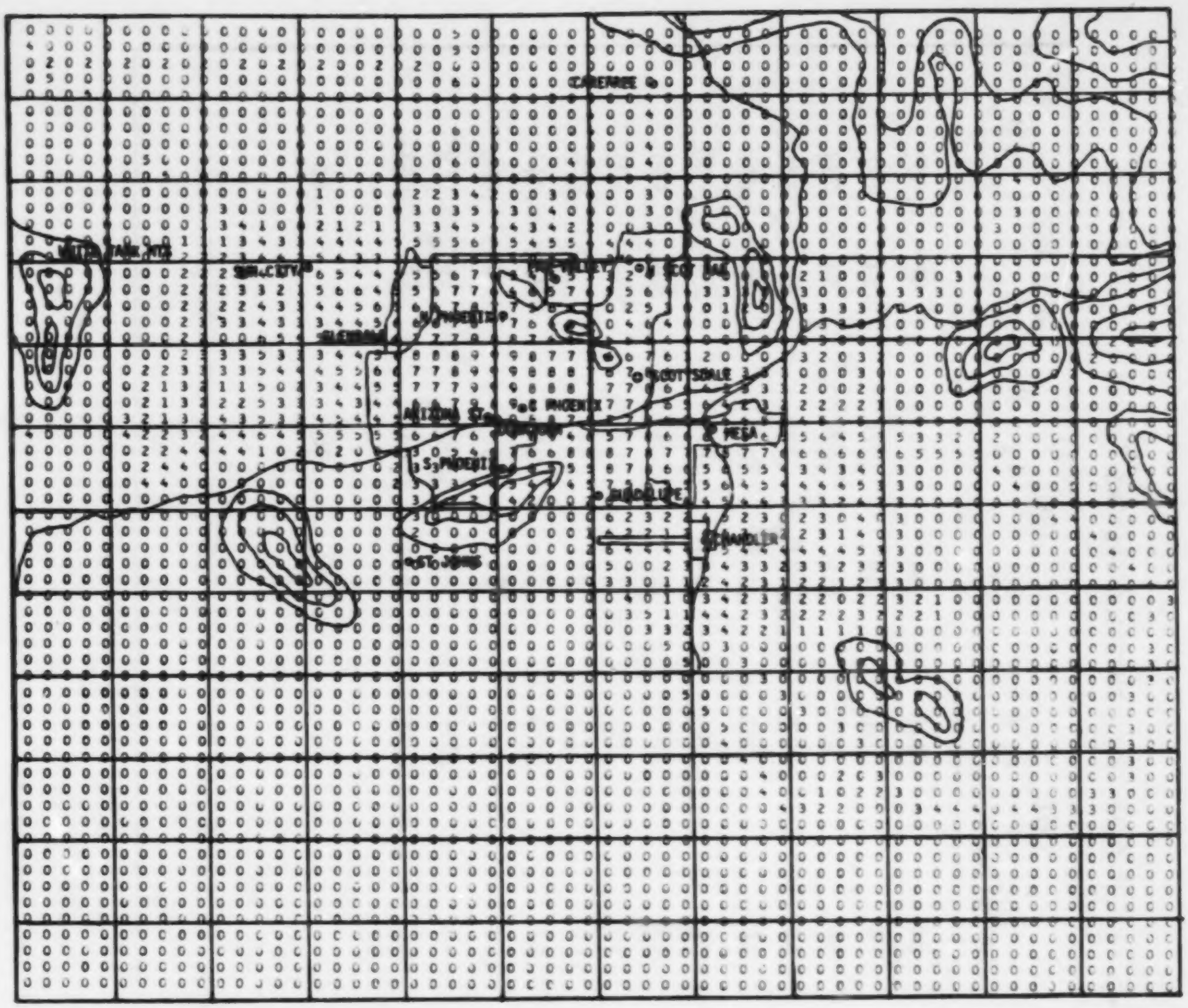
VEHICLE AGE	LDV FRACTION OF OF TRAVEL (M_o)	1975 E_o* (gm/mile)	1975 $E_o \times M_o$	1980 E_o	1980 $E_o \times M_o$	1985 E_o	1985 $E_o \times M_o$
1	.112	.25	.028	.54	.060	.54	.060
2	.143	.54	.077	.54	.077	.54	.077
3	.130	.54	.070	.54	.070	.54	.070
4	.121	.54	.065	.25	.030	.54	.065
5	.108	.54	.058	.25	.027	.54	.058
6	.094	.54	.051	.25	.024	.54	.051
7	.079	.54	.043	.54	.043	.54	.043
8	.063	.54	.034	.54	.034	.54	.034
9	.047	.54	.025	.54	.025	.25	.012
10	.032	.54	.017	.54	.017	.25	.008
11	.019	.54	.010	.54	.010	.25	.005
12	.013	.54	.007	.54	.007	.54	.007
≥13	.039	.54	.021	.54	.021	.54	.021
$\Sigma E_o \times M_o$			.51		.45		.51

* 1975 through 1977 vehicles have catalytic converters with lower emissions than pre 1975 or projected post 1977 vehicles.

TABLE 2-4. LIGHT DUTY TRUCK EMISSION FACTORS (gm/mi)

VEHICLE AGE	LDT FRACTION OF TRAVEL (M_o)	1975		1980		1985	
		E_o* (gm/mile)	$E_o \times M_o$	E_o	$E_o \times M_o$	E_o	$E_o \times M_o$
1	.094	.347	.033	.54	.051	.54	.051
2	.141	.54	.076	.54	.076	.54	.076
3	.132	.54	.071	.54	.071	.54	.071
4	.123	.54	.066	.347	.043	.54	.066
5	.098	.54	.053	.347	.034	.54	.053
6	.083	.54	.045	.347	.029	.54	.045
7	.076	.54	.041	.54	.041	.54	.041
8	.057	.54	.031	.54	.031	.54	.031
9	.044	.54	.024	.54	.024	.347	.015
10	.032	.54	.017	.54	.017	.347	.011
11	.023	.54	.012	.54	.012	.347	.008
12	.016	.54	.009	.54	.009	.54	.009
≥13	.081	.54	.044	.54	.044	.54	.044
$\Sigma E_o \times M_o$			.52		.48		.52

* 1975 through 1977 vehicles are assumed to be 2/3 catalyst and 1/3 non-catalyst.


CAREFREE
WHITE TANK MTS
SUN CITY
GLENDALE
N PHOENIX
SCOTTSDALE
ARIZONA ST
E PHOENIX
S PHOENIX
MESA
GUADALUPE
CHANDLER
ST JOHNS

GRID LEGEND

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00006
1	.00006 TO .00020
2	.00020 TO .00044
3	.00044 TO .00313
4	.00313 TO .00764
5	.00764 TO .01584
6	.01584 TO .02935
7	.02935 TO .05006
8	.05006 TO .08019
9	.08019 TO .12222

Figure 2-3. Grid Map for Particulate Emissions from Motor Vehicles, 1975.

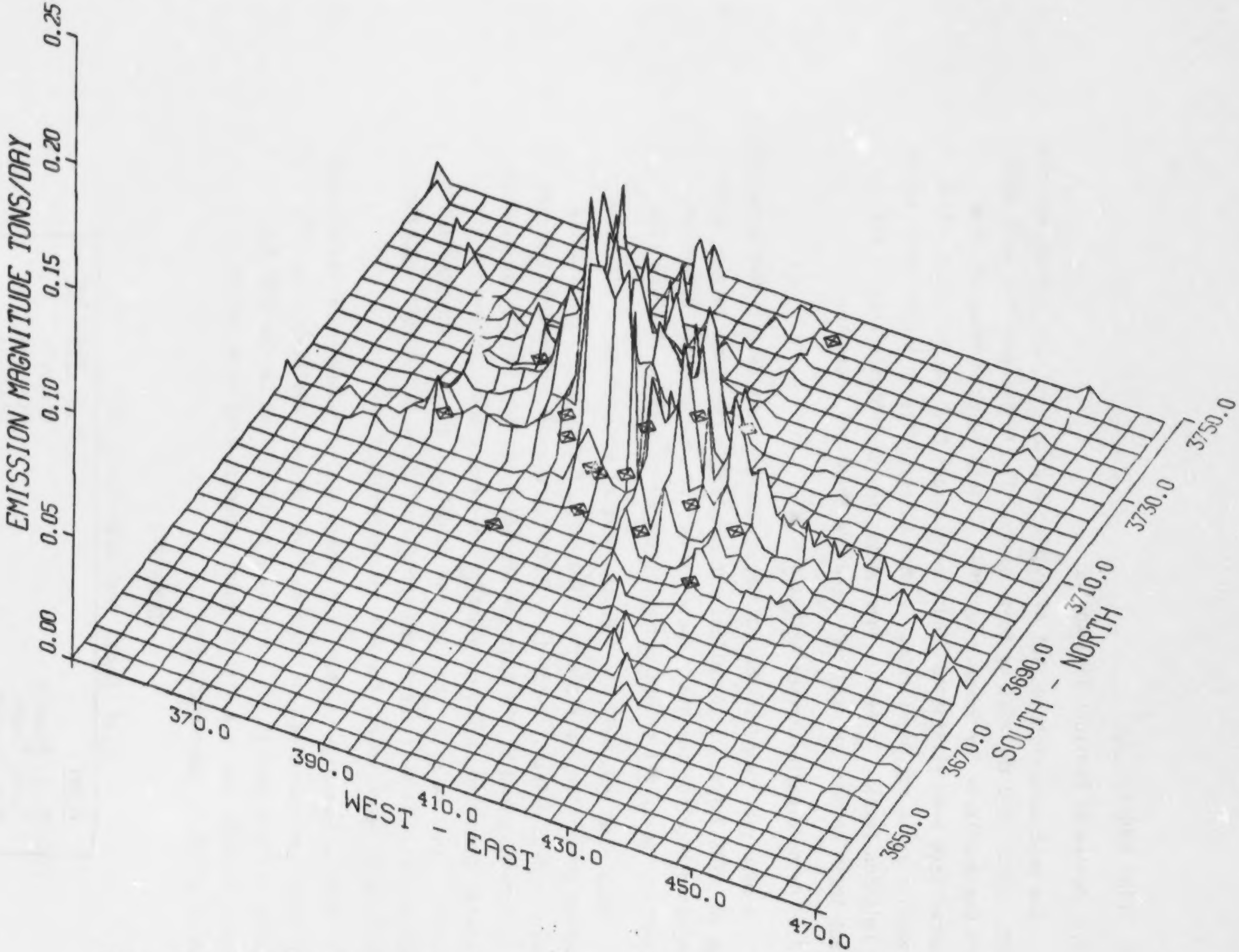


Figure 2-4. Average Daily Particulate Emissions from Motor Vehicles, 1975.

2.2 POINT SOURCES

2.2.1 Review of Previous Inventories

The most comprehensive set of available data for point sources was the NEDS. PEDCo used the NEDS in their study. The latest year for which NEDS data was available for Phoenix was 1972. Since 1972, various emission sources have been eliminated, and other sources have been created. Also, operating rates can be expected to change, resulting in significant changes in emission levels. Previous inventories for the Phoenix area do not reflect these changes in emissions, and are therefore, outdated.

2.2.2 Methodology of Present Inventory

A base year point source emissions inventory was established by adjusting the NEDS emissions to reflect current (1975) emissions levels, and a projected baseline inventory was developed by adjusting the base year inventory to reflect growth and attrition of sources by 1980 and 1985.

NEDS data from 1972 provided the bulk of information on all point sources other than power plants. Two emissions estimates are usually given in NEDS printouts; one is a "hand-calculated" estimate based upon knowledge acquired by the engineer preparing the data, while the other is computer generated, based on plant process rates and standard emission factors. In some cases the differences between the two estimates are substantial. It was, therefore, necessary to choose the more accurate estimate for each source for use in the emission model.

Discussions with the Maricopa County Health Department revealed that no local comprehensive point source inventory was available [6]. The county offered suggestions concerning modifications to the NEDS data. Shown in Table 2-5 is a list of point sources which were deleted as a result of these recommendations.

TABLE 2-5

POINT SOURCES SHUT DOWN SINCE 1972

PLANT	TYPE OF OPERATION
Teco, Phoenix	Minerals
Teco, Tempe	Minerals
W.R. Skouser	Minerals
T&C, Cattle	Grain
Buckeye City Dump	Open Burning
Tolleson City Dump	Open Burning

For the sources with especially large variance between hand and computer generated estimates, a separate calculation was performed in hopes of determining the most accurate estimate. These sources included for the most part the mineral companies. The operating rate and percent control efficiency were taken from NEDS and were multiplied together with an emission factor from AP-42 based upon the SCC code for each point source. The resulting emissions were then compared with the two estimates given in the NEDS printout. Shown in Table 2-6 are the point sources which were changed from the hand estimates given in the raw NEDS data. For four of the plants shown in Table 2-6 and indicated with an asterisk, fugitive dust emissions were included in the NEDS estimates. These were eliminated from the conventional portion of the inventory and are included later with the fugitive dust inventory.

Because of basic changes in fuel use patterns over the recent past, it was decided to update emissions at the local power plants. Since the 1972 NEDS data a new plant, Santan, was built to the southwest of Phoenix. Communications with personnel from the Arizona Public Service Company and the Salt River Project provided information on 1975 fuel use at the six power plants in the study area [7], [8]. Emission factors from AP-42 were applied to the baseline fuel use to get emissions in 1975. One plant (Cross Cut) in the Salt River Project was hardly used in 1975, and is expected to be shut down completely by 1980.

Power plants are the only conventional source for which a seasonal distribution of emissions is used. The generating facilities in the Phoenix area are primarily used as peaking plants to supplement the base load which is generated in northern Arizona. Therefore the seasonal variance in emissions is substantial.

2.2.3 Emission Estimates

Using the data described in Section 2.2.2, the emissions estimates for 1972 were compiled. Shown in Table 2-7 are the baseline estimates and totals for major point sources. All point sources given in NEDS are included in the inventory. Only the major sources are called out in that table for brevity. Table 2-8 gives the seasonal and annual average emissions for power plants. The projections of 1972 data to 1975, and other years are given in Section 5.1. Total point source emissions in 1975 are 21.6 tons/day. Figures 2-5 and 2-6 give the graphical representations for point source emissions (refer to Section 2.0 for explanation of graphics).

TABLE 2-6. CHANGES TO NEDS DATA

PLANT	NEDS ESTIMATES HAND (T/yr)	NEDS ESTIMATES COMPUTER (T/yr)	TRW ESTIMATE	ESTIMATE USED.
* Arizona Sand & Rock (1801 E. University)	1590	558	371	371
Beeline Sand & Rock	182	1	1	1
Phoenix Sand & Rock	497	2	2	2
Renolds Metal	1140	589	600	600
Suncrest Poultry	40	66	42	42
Johnson Stewart Metals	45	164	164	164
Union Rock & Mat'l (Hayden Road)	75	215	215	215
* Cons Concrete & Supply (El Mirage Road)	130	163	56	56
* Cons Concrete & Supply (W. Broadway)	197	184	40	40
* Arizona Sand & Rock (Agua Fria Pl.)	316	316	202	202
Phoenix Sand & Rock	128	150	128	128
Tri-City Redy Mix	13	-	19	19

* The NEDS estimates included fugitive emissions which are considered in the fugitive inventory of this study.

TABLE 2-7. POINT SOURCE ESTIMATES

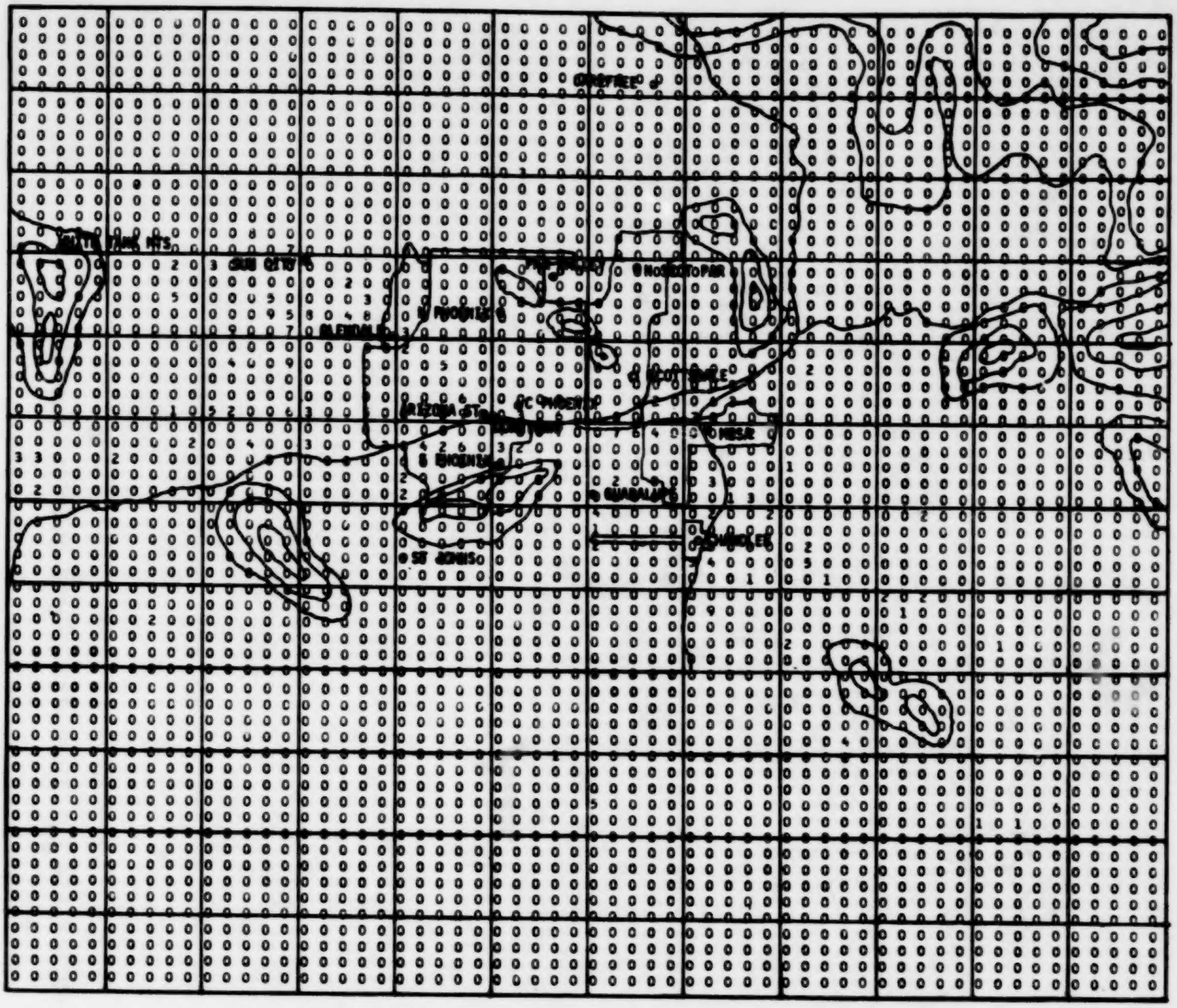
PLANT	ACTIVITY	EMISSIONS (TONS/DAY)
Renolds Metal	Metals	1.64
Royal Sand Co	Minerals	0.51
Teco, West	Minerals	0.88
Union Rock		
Beeline	Minerals	0.21
S. Central	Minerals	0.95
Hayden Road	Minerals	0.59
United Metro		
40th St.	Minerals	0.14
S. 19th Ave	Minerals	0.19
99th St.	Minerals	1.69
Glendale Ave.	Minerals	0.11
Valley Redi-Mix	Minerals	0.36
Bogle Farms	Grain & Cotton	0.18
Feeders Grain Co.	Grain	1.29
Suncrest Poultry	Grain	0.12
Gila Feed Yards	Grain	0.56
Circle One Livestock	Grain	0.79
Allied Concrete	Minerals	0.12
Quick Seed & Feed	Grain	0.56
Southwest Coop.	Grain	0.24
Johnson-Stewart Metals	Metals	0.45
S&D Cattle	Grain	0.19
Hayden Flour Mills	Grain	0.43
Maricopa Packing Feed Lot	Grain	0.15
Southwest Feed	Grain	0.19
Cons Concrete		
El Mirage Road	Minerals	0.15
W. Broadway	Minerals	0.11
Arizona Sand & Rock		
Agua Fria Pl.	Minerals	0.59
E. University	Minerals	1.01
Spreckles Sugar	Sugar Beet Process	1.34
Phoenix Sand & Rock	Minerals	1.57
Southwest Salt	Minerals	1.21

TABLE 2-8. SEASONAL DISTRIBUTION OF POWER PLANT EMISSIONS
(tons of particulates/day)

	JFM	AMJ	JAS	OND	ANNUAL AVERAGE
Cross Cut	0	.002	.001	0	.001
Agua Fria	1.040	0.964	1.328	0.901	1.058
Kyrene	0.295	0.243	0.288	0.158	0.246
Santan*	0	0	0.020	0.429	0.113
Octillo**	0.321	0.298	0.410	0.279	.327
West Phoenix**	0.163	0.151	0.208	0.141	.166
TOTALS	1.819	1.658	2.255	1.908	1.911

* Santan began operations in the summer, 1975.

** Since seasonal data were not available, these were assumed distributed proportionally to Agua Fria.


CAREFREE
WHITE TANK MTS
SUN CITY
GLENDALE
N PHOENIX
SCOTTSDALE
ARIZONA ST
C PHOENIX
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID LEGEND

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00000
1	.00000 TO .00271
2	.00271 TO .01371
3	.01371 TO .04334
4	.04334 TO .10582
5	.10582 TO .21943
6	.21943 TO .40653
7	.40653 TO .69351
8	.69351 TO 1.11088
9	1.11088 TO 1.69315

Figure 2-5. Grid Map for Particulate Emissions from Point Sources, 1975.

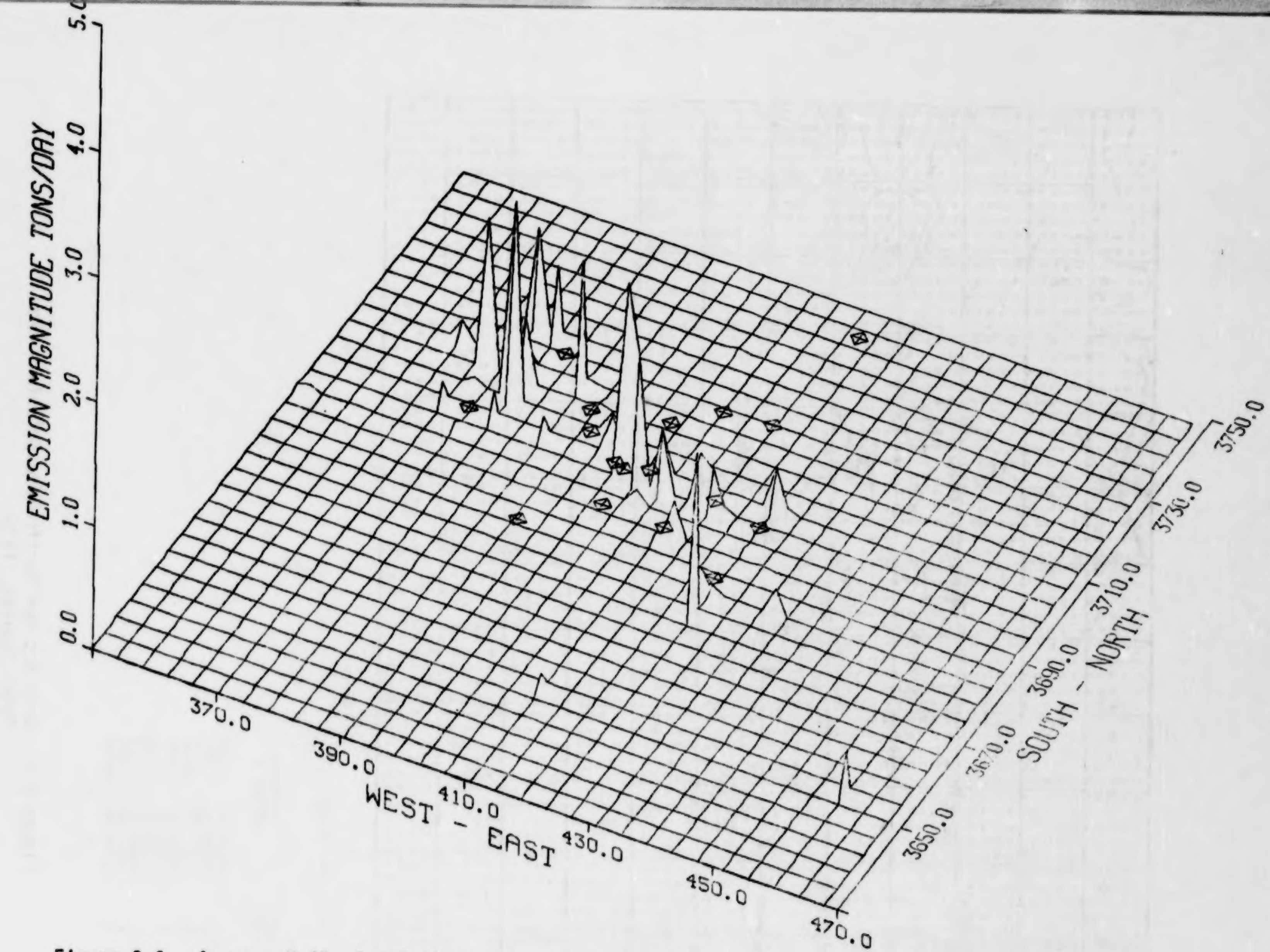


Figure 2-6. Average Daily Particulate Emissions from Point Sources, Fourth Quarter, 1975.

2.3 STATIONARY AREA SOURCES

2.3.1 Review of Previous Inventories

Quantification of area source emission levels in previous inventories has been limited by reliance on 1972 NEDS data as the most current information available. PEDCo used this data for their inventory. Since open burning for the most part has been eliminated, and space heating fuel use may have changed with the beginning of the fuel shortage in 1973, it seemed evident that reliance upon NEDS might produce large errors.

2.3.2 Methodology and Emissions of Present Inventory

Area fuel use data for Arizona was taken from two Department of Interior publications [9, 10]. The state figures were reduced by a factor of .55 (the percent of state population residing in Maricopa County in 1970) to reflect the area fuel use data for Maricopa County. Emission factors from AP-42 were applied to calculate emissions. Population growth was used to project fuel consumption from 1973 and 1974 to 1975. Table 2-9 gives fuel use and emissions for the three years.

The total non-mobile area source emissions were distributed to the grid system according to population. A 1970 census tract map was used to estimate the number of residents in each grid square. The emissions were then allocated to each grid square proportionally to the population in it.

A graphical representation of area source emissions is given in Figures 2-7 and 2-8. Since these emissions were distributed proportional to population density, these figures can also be interpreted as a population distribution. The three-dimensional picture gives a good description of the heavily populated area of Maricopa County.

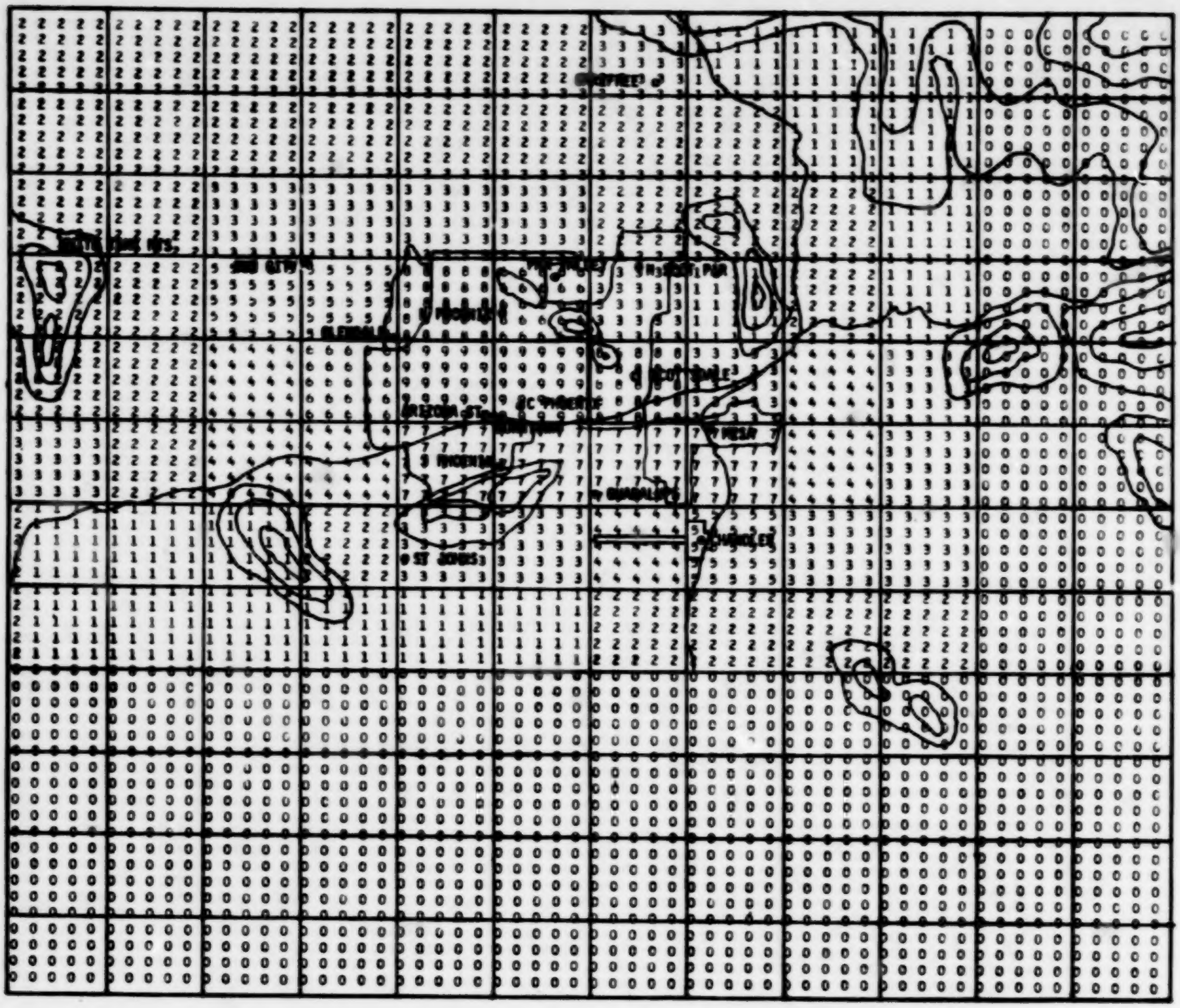
2.4 AIRCRAFT

2.4.1 Review of Previous Inventories

As with area sources, the source of information used in deriving previous inventories was the 1972 NEDS data. The NEDS provides a single total for county wide aircraft fuel use, and includes no information suitable for the spatial distribution of aircraft emissions.

TABLE 2-9. AREA FUEL USE AND EMISSIONS

	1973	1974	1975
Distillate Oil			
Consumption (10^3 BBL/year)	434.5	-	495.1
Emissions (Tons/year)	136.8	-	156.0
Natural Gas			
Consumption (10^6 ft^3/year)	-	34648	36907
Emissions (Tons/year)	-	329.2	350.6
Total Emissions			
Tons/Year	-	-	506.6
Tons/Day	-	-	1.39


SUN CITY
GLENDALE
PHOENIX
SCOTTSDALE
ARIZONA ST
MESA
GUADALUPE
CHANDLER
ST JOHNS

GRID LEGEND

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00000
1	.00000 TO .00002
2	.00002 TO .00008
3	.00008 TO .00027
4	.00027 TO .00065
5	.00065 TO .00136
6	.00136 TO .00251
7	.00251 TO .00428
8	.00428 TO .00686
9	.00686 TO .01046

Figure 2-7. Grid Map for Particulate Emissions from Area Sources, 1975.

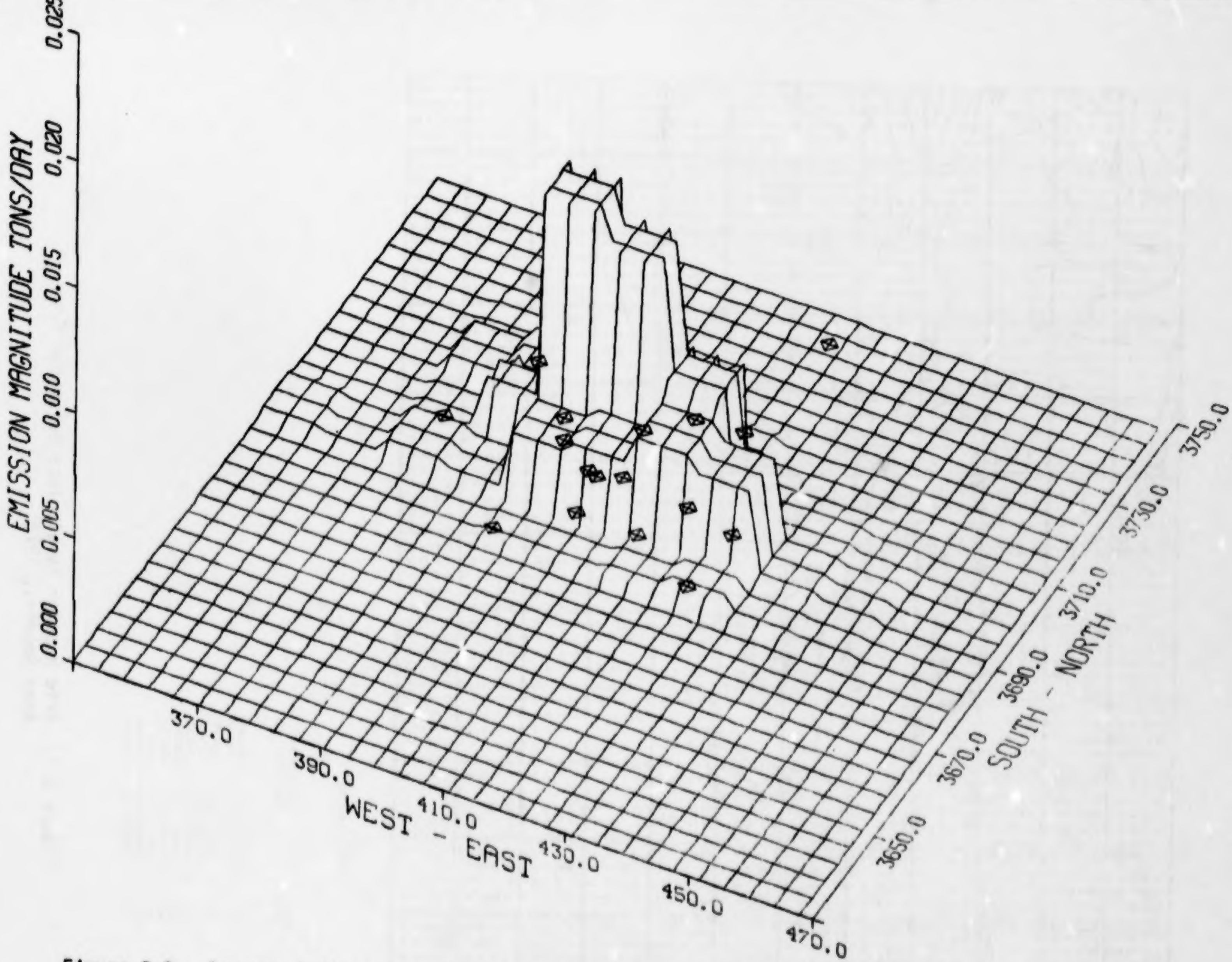


Figure 2-8. Average Daily Particulate Emissions from Area Sources, Fourth Quarter, 1975

2.4.2 Methodology and Emissions for Present Inventory

Data for aircraft activity at all civilian airports in the Phoenix area were obtained from the Airports Division of the Federal Aviation Administration in Los Angeles. Activity at military airports was obtained by telephone calls to the two air force bases in the area.

After review of the available data for all airports, it was decided to limit the analysis to only those airports which made a significant contribution to regional particulate air quality. Therefore, five metropolitan airports and two military bases were analyzed for emissions. The results are presented in Table 2-10.

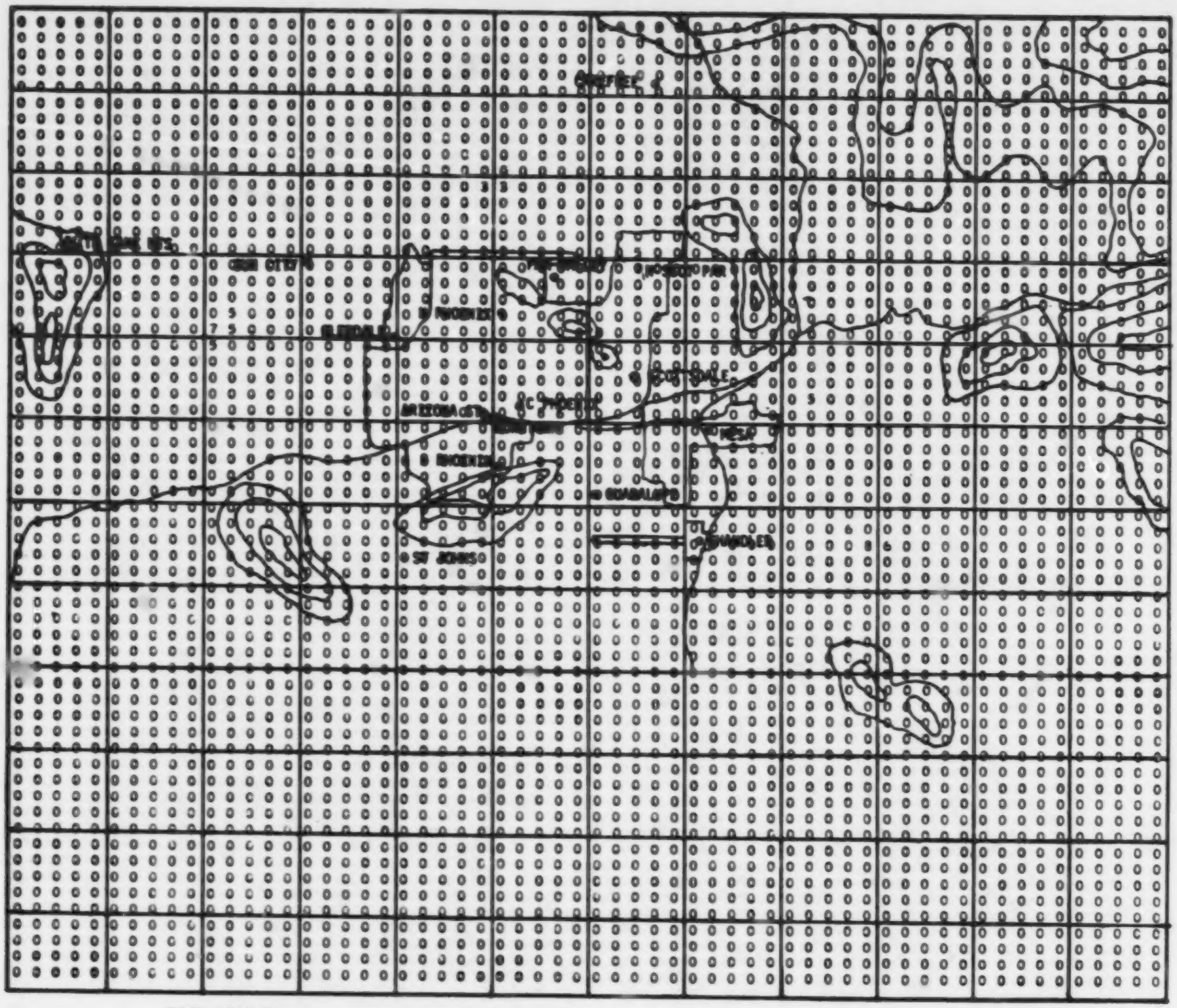
The emissions for each airport were distributed only to the grid squares in which they are located. This distribution technique is given in Table 2-11. The grid squares in this table are 1 kilometer square, and the UTM coordinates are those of the southwest corner of the grid square. The graphical representation of aircraft emissions is presented in Figures 2-9 and 2-10.

TABLE 2-10. EMISSION ESTIMATES FOR AIRCRAFT

AIRCRAFT	1975 EMISSIONS (TONS/DAY)
Sky Harbor	.190
Falcon Field	.008
Scottsdale	.007
Phoenix Litchfield	.004
Phoenix Dear Valley	.003
Williams AFB	.093
Luke AFT	.054
TOTAL	.358

TABLE 2-11. AIRPORT LOCATIONS

	UTM X	UTM Y	PERCENTAGE OF AIRPORTS IN GRID
1. Phoenix Litchfield	372	3698	15
	372	3699	45
	373	3699	40
2. Falcon Field	432	3702	50
	433	3703	50
3. Phoenix Dear Valley	398	3728	25
	399	3728	25
	400	3728	25
	401	3728	25
4. Sky Harbor	404	3699	5
	404	3700	10
	405	3699	40
	405	3700	15
	406	3699	20
	406	3700	10
5. Scottsdale Municipal	414	3721	50
	415	3721	50
6. Williams AFB	437	3686	20
	438	3685	20
	439	3685	20
	439	3684	20
	440	3684	20
7. Luke AFB	370	3709	15
	370	3710	15
	371	3710	20
	371	3711	20
	372	3711	15
	372	3712	15


CAREFREE
SUN CITY
GLENDALE
N PHOENIX
SCOTTSDALE
ARIZONA ST
C PHOENIX
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID LEGEND

GRID CODE	EMISSIONS TONS/DAY		
0	0.00000	TO	.00000
1	.00000	TO	.00014
2	.00014	TO	.00069
3	.00069	TO	.00219
4	.00219	TO	.00534
5	.00534	TO	.01108
6	.01108	TO	.02053
7	.02053	TO	.03502
8	.03502	TO	.05610
9	.05610	TO	.08550

Figure 2-9. Grid Map for Particulate Emissions from Aircraft, 1975.

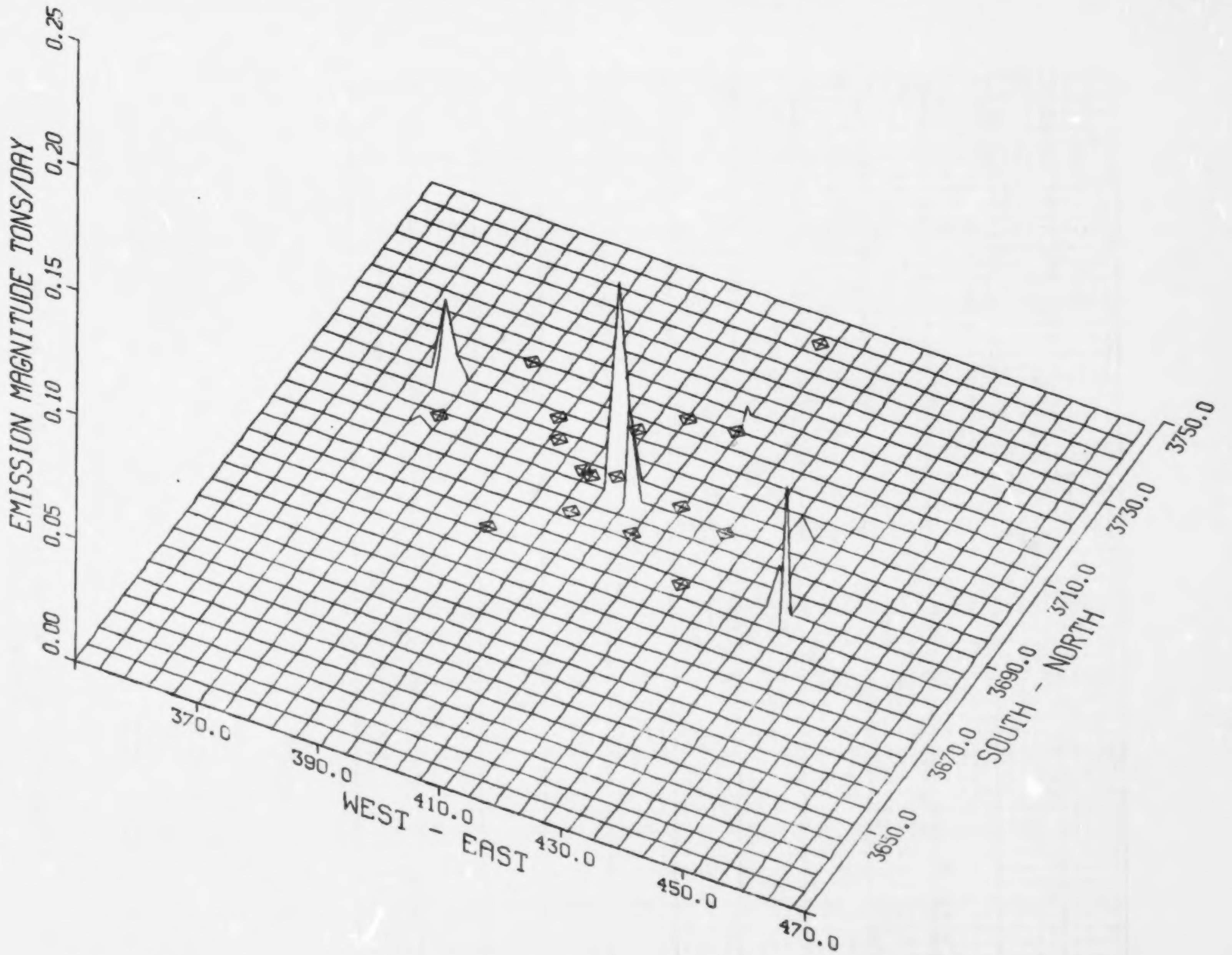


Figure 2-10. Average Daily Particulate Emissions from Aircraft, Fourth Quarter, 1975.

2.5 PARTICLE SIZE DISTRIBUTIONS

Particle size data presented in this section are in one of two forms. If a source type is equipped with controls (as specified by the Maricopa County Air Pollution Control District), size distributions for the controlled emissions are given. Otherwise, uncontrolled size distributions are reported. The efficiencies of the control were extrapolated from Figures 2-11 and 2-12.

For many source categories, particle size data were scarce or unavailable. Thus, extrapolations and assumptions were necessary. The impact of these assumptions is minimized by the relatively minor contribution of conventional sources to the total emissions inventory.

Motor Vehicles

Five categories of motor vehicles are present in the study area: light duty vehicles (LDV), light duty trucks (LDT), heavy duty gasoline vehicles, heavy duty diesel vehicles and motorcycles. Data for only one category, light duty vehicles, could be located and only for those light duty vehicles using low-lead fuels.

It is assumed that the particle size distributions characteristic of LDV's burning unleaded fuels and without catalytic mufflers are representative of the size distribution of all motor vehicles. This distribution is as follows:

Particle Diameter (μ)	Weight Percent
<1	60
1-2	25
>2	15

Source: Reference [13]

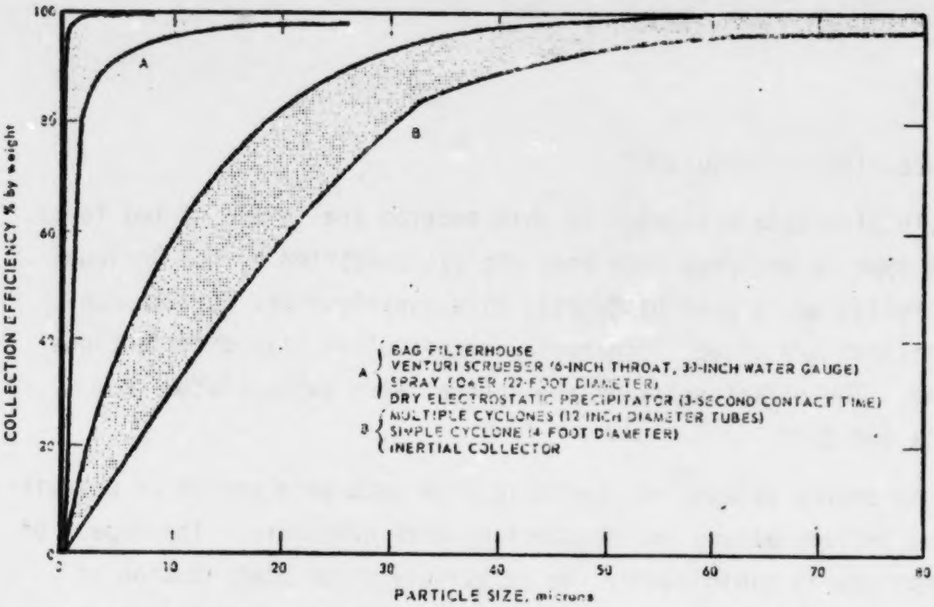


Figure 2-11. Composite Grade Efficiency Curves Based on Test Silica Dust
Source: Reference [11]

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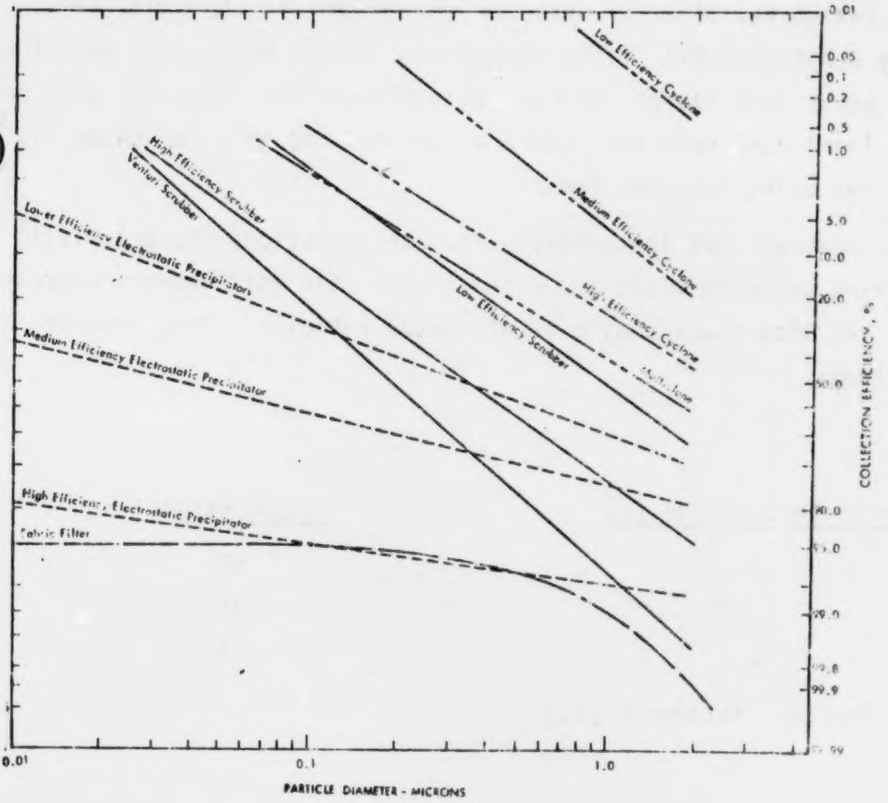

Figure 2-12. Extrapolated Efficiency of Control Devices
Source: Reference [12]

Aircraft

No published studies could be located pertaining to particle size distributions. It is assumed that the distributions for motor vehicles will apply to aircraft.

Stationary Point Sources

The major point sources within the study area may generally be classified into four categories (see Table 2-7 and 2-8): the mineral industry, metals industry, agricultural processes, and power plants.

Metals - the only metal industry plant belongs to Reynolds in Phoenix. According to the NEDS point source listing, the particulate emissions result from the chlorinating station, where the magnesium content is reduced by lancing chlorine gas into the molten metal. No control equipment is utilized. Particle size distribution is as follows:

Particle Diameter (μ)	Weight Percent
<1	90
<2	100

Source: Reference [14]

Power Plants - all the power plants listed in Table 2-8 presently burn distilled fuel oil.* Size distribution data for distillate is not available; thus, data for residual fuel oil is assumed to apply:

Particle Diameter (μ)	Weight Percent
<1	88
1-2	7
2-5	3
>5	2

Source: adapted from [14]

---

*In 1975, a very small percentage of the fuel used was natural gas. It is not expected that any of these plants will receive natural gas in the future. No power plants in Maricopa County burn coal.

Minerals- the processes conducted by the mineral industries are comprised of three categories: crushing and screening rock and sand, concrete batching and asphaltic mixing. An average size distribution for the overall emissions can be specified as follows:

Particle Diameter (μ)	Weigth Percent
<2	5
2-20	27
>20	68

Source: Reference [12]

(The Maricopa County APCD reports that spray bars are used at the crusher and transfer points. However, no control efficiencies were found in the literature for these devices. Therefore, uncontrolled sized distributions were assumed.)

Agricultural Processes - industries in this category are mainly involved with grain storage and shipment. As could be expected, no information on size distributions could be found. Thus, it is assumed that the distributions for numeral industries will apply to agricultural processes.

Stationary Area Sources

Emissions from area sources are the result of burning distillate fuel oil for space heating. Particle size distributions for power plants are assumed to be applicable for area sources.

REFERENCES FOR SECTION 2.0

1. PEDCo Environmental Specialist, "Investigation of Fugitive Dust Volume I - Sources, Emissions, and Control," EPA-450/3-74-036-a.

2. Communication with Ellwood C. Neiman of the Transportation Planning Division of the Arizona Department of Transportation, March 1976.

3. Arizona Department of Transportation, "Arizone Traffic FA-FAS State Routes 1974," Planning Survey Group, 1975.

4. Telephone communication with Ed. Baldwin of the Maricopa County Auto License Department, 3-15-76.

5. EPA, "Supplement No. 5 for Compilation of Air Pollutant Emission Factors," Second Edition, December 1975.

6. Telephone communication with Greg Witherspoon of the Maricopa County Health Department, March and April 1976.

7. Communication with James R. Weiss of Arizona Public Service Company, Phoenix, April 1976.

8. Communication with Don Moon of the Salt River Project, Phoenix, April 1976.

9. U.S. Department of Interior, "Sales of Fuel Oil and Kerosine in 1973," Mineral Industry Survey, 9-5-74.

10. U.S. Department of Interior, "Natural Gas Production and Consumption: 1974," Mineral Industry Surveys, 8-29-75.

11. U.S. Department of Health, Education and Welfare, "Control Techniques for Particulate Air Pollutants," National Air Pollution Control Administration, Washington, D.C., 1969.

12. Midwest Research Institute, "Particulate Pollutant System Study, Volume II," prepared for the Environmental Protection Agency, Contract No. CPA-22-69-104, 1971.

13. The Dow Chemical Company, "Characterization of Particulates and Other Non-Regulated Emissions from Mobile Sources and the Effects of Exhaust Emissions Control Devices on these Emissions," APTD-1567, March 1973.

14. U.S. Environmental Protection Agency, "Air Pollution Engineering Manual," Publication No. AP-40, 1973.

3.0 BASEYEAR ANTHROPOGENIC SOURCES OF FUGITIVE DUST

For the context of this study, anthropogenic fugitive dust sources are considered to be those resulting directly from, and during, human activities. Specifically, these are motor vehicles on unpaved roads, agricultural tilling, cattle feedlots, off-road motor vehicles, construction activities, and dust suspended by motor vehicles on paved roads. Fugitive dust emissions from aggregate storage, caused by both anthropogenic and natural causes (wind erosion), are also evaluated in this section.

Table 3-1 summarizes the baseyear emissions of fugitive dust from anthropogenic sources in the study area. The largest source by far is motor vehicles travelling on unpaved roads. Not surprisingly, these emissions are distributed mainly in the rural areas of Maricopa and northern Pinal Counties. The factor having the greatest influence on the emissions is the silt content of the road surface, which can be as high as 27% for some dirt roads. Construction activities are the next major source of fugitive dust, contributing about 100 tons/day. Off-road motor vehicles, which includes motorcycles, contribute the third largest percentage of the total inventory. The remaining three sources are relatively minor, as compared to the latter emitters. Agricultural tilling operations are seasonal in nature and range from a high of over 30 tons/day during the spring quarter to a low of just over 1.5 tons/day during the summer quarter. Emission levels from aggregate storage and cattle feedlots are yet more insignificant, especially considering that these sources are generally located in rural areas.

3.1 MOTOR VEHICLES ON UNPAVED ROADS

This section documents the methodology employed to estimate the magnitude and distribution of dust emissions arising from motor vehicle travel on unpaved roads. In Section 3.1.1, previous emission inventories conducted for the study area are reviewed to select an appropriate emission model for the present study. Section 3.1.2 describes field tests conducted to permit area-specific characterizations of unpaved road surfaces, and tabulates transportation network data to estimate total mileages and spatial

TABLE 3-1. SUMMARY OF BASELINE ANTHROPOGENIC FUGITIVE DUST EMISSIONS IN THE STUDY AREA

Source Category	Emissions (tons/day)
Motor Vehicles on Unpaved Roads	1281
Agricultural Tilling Operations	
Winter	22
Spring	31
Summer	1.3
Fall	17
Aggregate Storage	.06
Cattle Feedlots	7.5
Off-Road Motor Vehicles*	71
Construction Activities	100

* Off-road vehicle emissions are generated almost entirely over the two-day weekend period (see Section 3.5 for further explanation).

distribution of unpaved roadways. An emissions model is then used to generate emissions estimates.

3.1.1 Review of Previous Inventories and Emission Factors

A literature search was conducted to obtain results of previous research in the development of fugitive dust emission factors from motor vehicles traveling on unpaved roads (see Table 3-2). The factors of greatest interest to this study were those derived by the Midwest Research Institute (MRI) and PEDCo Environmental Specialists, Inc. (PEDCO) as they were the results of extensive testing and analyses programs. The remainder of this section will be devoted to a review of MRI's and PEDCO's work.

A basic assumption underlying the development of the PEDCo emission factor is that heavy traffic (five vehicles per minute) across an unpaved road approaches the condition of a continuously-emitting infinite line source, as described by Sutton [14]. Sampling data of particulate concentrations were taken by a beta gauge airborne dust sampling/readout instrument positioned at various distances (from 55 to 300 feet) and heights (from 3 to 100 feet) downwind of the road. Ambient data were substituted into Sutton's equation to solve for the source emission rate. An equation was then derived which expressed the relationship between vehicle speed and emission rate over the range of speeds investigated:

$$E = (0.16)\ (1.068)^{x} \qquad (1)$$

where

E = emissions, lbs/vehicle-mile

x = vehicle speed, miles/hour

TABLE 3-2. FUGITIVE DUST EMISSION FACTORS FOR UNPAVED ROADS

INSTITUTION PERFORMING STUDY	EMISSION FACTOR	COMMENTS
Midwest Research Institute [1]	$e = 0.81\ s\left(\frac{S}{30}\right)$ where e = emission factor, lbs/vehicle-mile s = silt content of road surface material (percent) S = average vehicle speed, miles/hour	• Factor assumes a linear dependence on vehicle speed from 30 to 50 mph. • Factor is accurate for 4-wheeled vehicles and must be adjusted for all other types of vehicles. • No emissions are assumed for days with rainfall greater than 0.01 inches. • Silt is defined to be particles with a diameter less than 75μ. • Factor is applicable for particles with a drift potential of greater than 25 feet, i.e., particles less than 100μ in diameter • For vehicle speeds below 30 mph, emissions increase in proportion to the square of the vehicle speed. • Accuracy of the factor is ± 10%.
PEDCo Environmental Specialists, Inc. [2]	$E = (0.27)(1.068)^{x}$ where E = emission factor, lbs/vehicle-mile x = vehicle speed, miles/hour	• Factor is valid for vehicle speeds from 15 to 40 miles/hour.
University of New Mexico [3]	0.93 lbs/vehicle-mile for particles <6μ 0.04 lbs/vehicle-mile for particles <3μ	• Vehicle speed during testing was 25 miles/hour.
University of Iowa [4]	5.5 lbs/vehicle mile	
C. Anderson [5]	0.5 - 0.7 lbs/vehicle-mile	• Vehicle speed during testing was 30 miles/hour.
Pudget Sound (Washington) Air Pollution Control Agency [6]	3.5 lbs/vehicle mile at 10 miles/hour 7.0 lbs/vehicle mile at 20 miles/hour 22.2 lbs/vehicle mile at 30 miles/hour	

This equation, however, was corrected to account for the fact that the beta gauge samples a narrower range of particle sizes than the Hi-Vol samples, on which the particulate ambient air quality standards are based. Hi-Vol data, taken concurrently with the beta samples, were used to determine the ratio and correlation between readings of the two types of samples. As a result, equation (1) was adjusted upward by a factor of 1.68, yielding the emission factor:

$$E = (0.27)\ (0.068)^x \tag{2}$$

where

E = emissions, lbs/vehicle-mile

x = vehicle speed, miles/hour

The major weakness in the PEDCo factor is that the "dustiness" (or quantity of fine dirt particles) on the road surface is not considered. Another weakness lies in the assumption that heavy traffic (five vehicles per minute) approximates an infinite continuously-emitting line source. An emission factor developed from such an assumption may not hold true for vehicular traffic of lower volumes, which is the case in rural Arizona. One final weakness is that background concentrations of particulates were not discounted in determining the emission factor. It should be noted that the primary intent of the PEDCo contract was not, specifically to development of emission factors, but to develop control regulations to achieve air quality standards.

MRI also employed a field sampling program to develop their emission factor. These tests included the use of isokinetic samplers located at set heights and at distances greater than 20 feet from the road. Hi-Vol samples were also taken to correct for background dust concentrations. The following equations were used in developing the final factor:

$$e_{<2} = ER_6\ F_{<2} \tag{3}$$

$$e_{2-30} = ER_6\ (1-F_{<2}) \tag{4}$$

$$e_{>30} = E\ (1-R_6) \tag{5}$$

where

e_i = mass of dust emissions with diameter i per vehicle-mile

E = integrated exposure measurement

R_6 = ratio of dust concentration measured by the standard Hi-Vol to the concentration measured by the isokinetic profiler, at 6-ft. height.

$F_{<2}$ = fraction of the particles smaller than 2μ in diameter, measured by high-volume cascade unpaction.

The only previous inventory accounting for fugitive dust emissions from dirt roads in Phoenix was performed by PEDCo [2]. PEDCo's methodology was realitvely standard and straightforward. Exact mileages of unpaved roads by county were obtained from state highway department annual reports on the status of the highway system. Where available, exact traffic counts were used; otherwise, estimates obtained from state and county highway officials were employed. An average vehicle speed of 30 miles/hour representing the low of several estimates given by highway department officials, was assumed. With these data, total emissions were obtained by simple multiplication.

Of more interest was the determination of emissions on a gridded basis. This was performed for Easter Maricopa and Pima Counties. Mileages of unpaved roads within a given grid were measured off a county map illustrating the unpaved roads. Average daily traffic values were obtained from a county highway map. Presumably, the same average vehicle speed, 30 miles/hour, was assumed. In conversations with the Maricopa County Highway Department [8], however, it was discovered that this approach introduced accuracies in both the mileages and average daily traffic counts. This is because the maps utilized are incomplete for both categories of data.

3.1.2 Methodology of the Present Inventory

This section will detail the approach utilized in estimating fugitive dust emissions from motor vehicles traveling on unpaved roads. Topics discussed are: (1) selection of an emission factor, (2) mileages and distribution of unpaved roads, (3) vehicle speed, (4) average daily traffic, and (5) silt content of road surfaces, and (6) effect of rainfall. Items (2) through (6) serve as inputs to the estimation process.

Emission Factor Selection

Table 3-2 presents the various emission factors available for use. The primary selection criteria for this study was the number of "influence categories" considered in the factor - i.e., vehicle speed, vehicle type, road surface type. Also important were the test procedures employed in deriving the factor. These include number of tests, type of analyses performed, sampling method and locale in which the testing was performed, Based on these criteria, the MRI emission factor was chosen, primarily because of the "influence categories" considered, but also because of the comprehensive flux measurements conducted in the field testing.

Mileages and Distribution of Unpaved Roads*

Because the emission inventory is to be utilized as an input to the modeling effort, a spatial resolution of the distribution and mileage of unpaved roads was mandatory. After consultation with knowledgeable personnel at various organizations [7,8,9], two candidate approaches were identified. The Maricopa County Highway Department has prepared a map illustrating traffic volumes for various roads. This map also differentiates road types. By overlapping a grid on this map and measuring road mileages, the distribution of unpaved roads can be determined. The disadvantages of this approach are twofold - (1) many existing unpaved roads are not included on the map, and (2) the map was prepared for the year 1974 and thus does not account for the construction of new dirt roads or the paving of existing ones in 1975. The second alternative and the one ultimately selected, involved manipulating road maintenance data from the Maricopa Highway Department.

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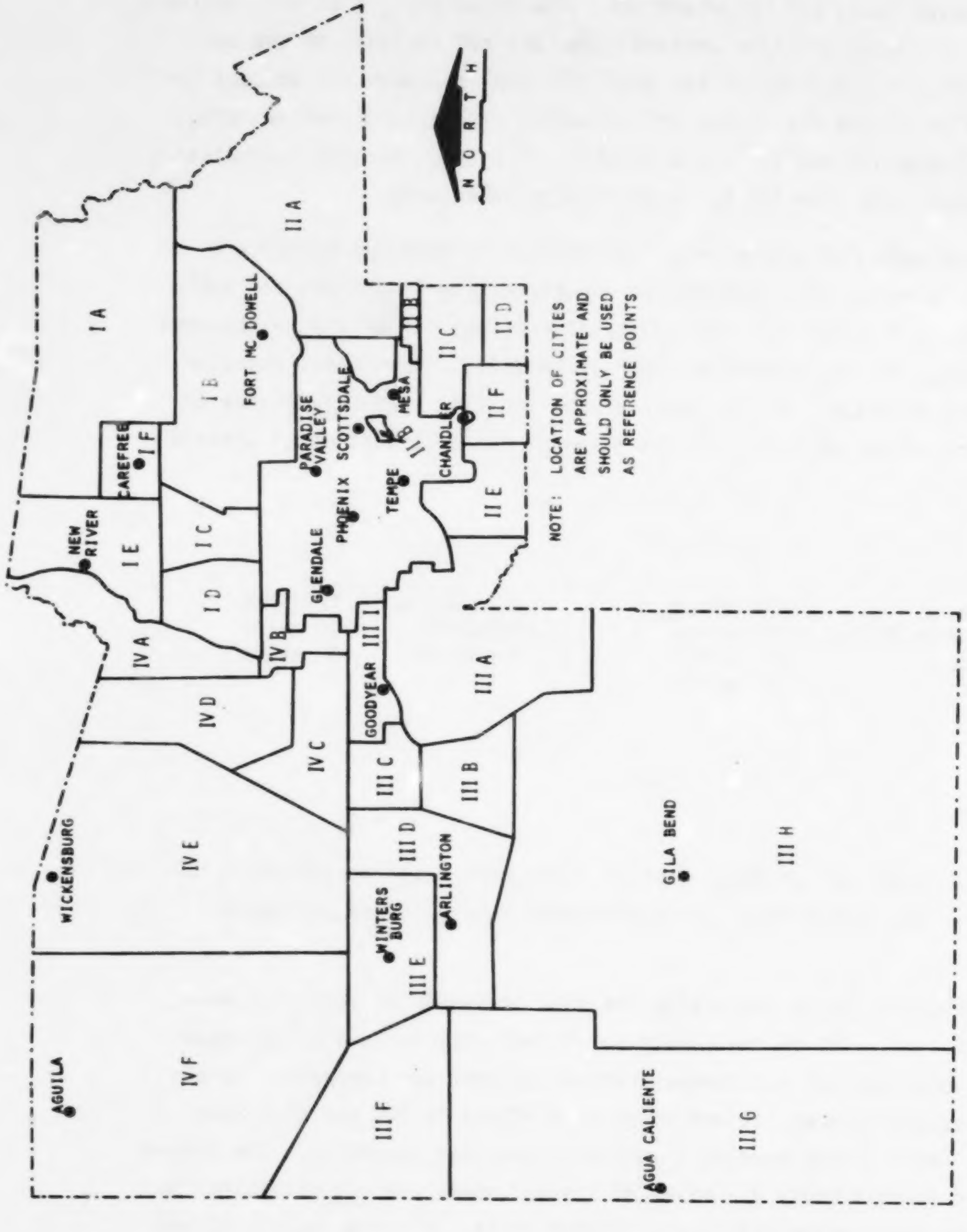
* For the purposes of this study, an unpaved road is one whose surface has not been subjected to any chemical treatment, such as bituminous coating. Within the study area of this project, unpaved roads are thus either dirt, stone or gravel topped.

The distribution of unpaved roads maintained by Maricopa County are summarized in terms of road maintenance districts (see Figure 3-1 and Table 3-3). It should be noted that the county is responsible for the maintenance of roads outside metropolitan areas such as Phoenix, Tempe, Mesa, Chandler, Scottsdale and Glendale. As for these areas, the city road maintenance departments were contacted to obtain the mileages and distribution of unpaved roads:

Phoenix	121 miles	Scottsdale	12 miles
Paradise Valley	10 miles	Glendale	10 miles
Tempe	3 miles	Chandler	4 miles
Mesa	17 miles		

No exact locations of these unpaved roads were readily available, so it is assumed that these roads are distributed evenly throughout these cities.

Two additional facts concerning the data presented in Table 3-3 must be mentioned. Only 70% of the county maintained dirt roads are accounted for, as the computerized maintenance records are not yet complete. To adjust for this discrepancy, it was decided to adjust by 30% the dirt road mileages in Table 3-3 to develop a more accurate road inventory. The second fact is that approximately 919 miles of unpaved roads are not maintained by the county in the various maintenance districts [8, 15]. Of these, 167 are in national forest areas, 36 in Indian Reservations, and 716 in the remainder of the county [15]. These mileages will be distributed as follows:


I A
I B
I C
I D
I E
I F
CAREFREE
NEW RIVER
FORT MC DOWELL
II A
II B
II C
II D
II E
II F
PARADISE VALLEY
SCOTTSDALE
PHOENIX
GLENDALE
TEMPE
MESA
CHANDLER
IV A
IV B
IV C
IV D
IV E
IV F
III I
III A
III B
III C
III D
III E
III F
III G
III H
GOODYEAR
WICKENSBURG
WINTERS BURG
ARLINGTON
GILA BEND
AGUILA
AGUA CALIENTE
NORTH

NOTE: LOCATION OF CITIES ARE APPROXIMATE AND SHOULD ONLY BE USED AS REFERENCE POINTS

Figure 3-1. Maricopa County Highway Department Road Maintenance Blading Districts

TABLE 3-3. SUMMARY OF MILEAGES OF UNPAVED ROADS MAINTAINED BY MARICOPA COUNTY- BY MAINTENANCE AREAS*

MAINTENANCE AREA	MILEAGE
1A	28.7
1B	76.47
1C	52.63
1D	51.57
1E	79.15
1F	77.68
2A	134.28
2B	94.41
2C	66.53
2D	71.88
2E	88.89
2F	20.50
3A	65.67
3B	96.45
3C	48.45
3D	53.6
3E	108.25
3F	80.45
3G	56.0
3H	96.50
3I	40.5
4A	91.56
4B	29.47
4C	53.00
4D	134.30
4E	76.20
4F	91.50

* Data as of March 2, 1976. The figures are estimated to account for approximately 70% of all county maintained unpaved roads.

National Forest Areas	167 miles equally between maintenance areas 1A, 1B, and 2A.
Indian Reservations	36 miles equally between maintenance areas 2B and 3A.
County	716 miles equally to all maintenance areas.

Based on the above considerations, total unpaved road mileages are tabulated. Table 3-4 illustrates the adjusted total miles of unpaved roads in Maricopa County, including both county maintained and non-county maintained roads for the area of each maintenance district.

For the portion of the study area in Northern Pinal County, a different procedure was required (maintenance data was not available for Pinal County). Maps from the Arizona State Department of Transportation illustrating the distribution of unpaved roads were obtained and mileages were extracted by measurement off the map. These are presented in Table 3-5.

Vehicle Speeds

Conversations with officials at the Maricopa County Highway Department indicated that PEDCo's estimate of 30 miles/hour was probably low, as vehicle speeds on unpaved roads were estimated to range from 30 to 40 miles/hour. For the purposes of this study, an average of 35 miles/hour is assumed, both for Maricopa and Northern Pinal Counties.

Silt Content of the Road Surface*

The determination of the silt content of the road surface is a crucial issue, as emissions are directly proportional to the percentage silt. All unpaved roads in Maricopa County are either dirt or gravel [8]. No exact percentages of each type are available, so the opinions of cognizant county highway personnel were solicited. As a result, a distribution of 60% dirt and 40% gravel of county maintained roads in each maintenance district for unpaved roads in Maricopa County is assumed. Roads not receiving county

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* For the purpose of the emissions model, silt is defined as particles with a diameter of 75μ (.075 mm) or less. The silt content is expressed as percent by weight.

TABLE 3-4. UNPAVED ROAD MILEAGES IN MARICOPA COUNTY

MAINTENANCE AREA	COUNTY MAINTAINED (ADJUSTED)	NO COUNTY MAINTENANCE
1A	41	82.1
1B	109.2	82.1
1C	75.2	26.5
1D	73.67	26.5
1E	113.07	26.5
1F	110.97	26.5
2A	191.83	82.1
2B	134.87	44.5
2C	95.04	26.5
2D	102.69	26.5
2E	126.99	26.5
2F	29.29	26.5
3A	93.81	44.5
3B	137.79	26.5
3C	69.21	26.5
3D	76.57	26.5
3E	154.64	26.5
3F	114.93	26.5
3G	80.00	26.5
3H	137.86	26.5
3I	57.86	26.5
4A	130.8	26.5
4B	42.1	26.5
4C	75.71	26.5
4D	191.86	26.5
4E	108.86	26.5
4F	130.71	26.5

TABLE 3-4. UNPAVED ROAD MILEAGES IN MARICOPA COUNTY (Continued)

CITY	MILEAGE
Phoenix	121
Scottsdale	12
Paradise Valley	10
Glendale	10
Tempe	3
Chandler	4
Mesa	17

TABLE 3-5. UNPAVED ROAD MILEAGES IN NORTHERN PINAL COUNTY

TOWNSHIP AND RANGE	DIRT (MILES)	GRAVEL (MILES)
T1N, R8E	14.0	10.0
T1N, R9E	0.2	2.0
T1N, R10E	10.0	0
T1N, R11E	0	0
T1N, R12E	0	0
T1N, R13E	2	0
T1S, R8E	7.5	0.5
T1S, R9E	10.0	8.0
T1S, R10E	16.0	2.5
T1S, R11E	15.0	0
T1S, R12E	3.0	2.2
T1S, R13E	8.0	2.0
T2S, R2E	11.0	0
T2S, R8	22.5	1.0
T2S, R9E	0.5	0
T2S, R10E	9.0	2.0
T2S, R11E	20.0	2.0
T2S, R12E	7.0	6.0
T2S, R13E	14.0	0
T3S, R2E	6.0	0
T3S, R3E	7.0	3.0
T3S, R4E	42.0	2.0
T3S, R5E	26.0	6.0
T3S, R6E	26.0	1.0
T3S, R7E	30.0	0
T3S, R8E	23.0	0
T3S, R9E	6.0	0
T3S, R10E	13.0	0
T3S, R11E	24.0	0
T3S, R12E	0	0
T3S, R13E	3.0	0
T4S, R2E	14.0	10.0
T4S, R3E	3.0	11.0
T4S, R4E	32.0	17.0
T4S, R5E	11.0	6.0
T4S, R6E	9.0	0
T4S, R7E	16.0	5.0
T4S, R8E	12.0	1.0
T4S, R9E	1.0	5.0
T4S, R10E	16.0	0
T4S, R11E	10.0	0
T4S, R12E	7.0	0
T4S, R13E	10.0	0
T5S, R2E	16.0	0
T5S, R3E	29.0	5.0
T5S, R4E	19.0	4.0
T5S, R5E	4.0	4.0
T5S, R6E	6.0	8.0
T5S, R7E	18.0	4.0
T5S, R8E	28.0	10
T5S, R9E	7.0	4
T5S, R10E	26.0	0
T5S, R11E	10.0	0
T5S, R12E	14.0	0
T5S, R13E	7.0	0
T6S, R2E	14.0	3.0
T6S, R3E	29.0	10.0
T6S, R4E	39.0	5.0
T6S, R5E	30.0	0.0
T6S, R6E	26.0	0
T6S, R7E	45.0	0
T6S, R8E	7.0	0
T6S, R9E	2.0	0
T6S, R10E	2.0	0

maintenance (second column in Table 3-4) are assumed to all be dirt surface. As for city maintained roads, the same 60/40 split is assumed. In Northern Pinal County, the maps from which mileages were obtained differentiated between dirt and gravel roads. Thus the distribution shown in Table 3-5 reflects the actual mileages.

Gravel roads possess a relatively low silt content. Numerous field measurements by MRI [10] show that an average of 12% silt is a reasonable figure. Officials in the Maricopa County Highway Department estimate a 10% silt in gravel roads [8]. For the purpose of this report, a 12% content is assumed in both Maricopa and Pinal Counties.

For dirt roads, it was unclear whether the particle size distribution of the road soil would be equivalent to that of the native soil. Consequently, field tests were conducted to determine the silt levels of unpaved roads selected to be representative of the predominant soil associations in the study area. Sampling and analysis procedures were consistent with the MRI approach used in developing the emissions model. Composite samples of road dust were collected by sweeping loose material from lateral strips of the road surface. The silt content of the road soil was determined by dry sieve screening. Table 3-6 shows the results of the analysis. It can be seen that the silt content of soils on unpaved road surfaces reaches an equilibrium value substantially less than that of the native soil. This is apparently caused by the continual removal of fines by vehicle traffic, leaving on the road surface a higher percentage of coarse particles than is observed in the native soil.

TABLE 3-6. CHARACTERIZATION OF SOIL MATERIAL ON UNPAVED ROADS IN PHOENIX AREA

Soil Type	Silt Content* of Road Surface	Silt Content* of Native Soil
Gilman-Estrella-Avondale	27.2%	55 - 80%
Mohal-Contine	14.2	55 - 80
Ebon-Pinaimt-Tremant	23.3	15 - 45
Rock Outcrop	12.4	10 - 30

* Silt content is defined as the percentage (by weight) of soil particles less than 75 micron in diameter.

A general soil map of Maricopa County [11] and Pinal County [19] were employed to establish the soil association in each of the designated maintenance areas and townships of the study area. Accordingly, a silt level was assigned to these cell areas as shown in Table 3-7.

Average Daily Traffic

The vast majority of unpaved roads in both Maricopa and Northern Pinal Counties are not monitored for traffic counts. Because no substantial alternative means of estimating daily traffic volumes were apparent, a modified version of average daily traffic (ADT) figures obtained by PEDCo [2] (see Table 3-8) was utilized. The modified version accounts for two categories of unpaved roads - dirt and gravel, whereas PEDCo included four road types. The following consolidation was made:

PEDCo Road Types	TRW Road Types
Primitive Unimproved	Dirt- no maintenance
Graded and Drained	Dirt- city or county maintained
Rock, Gravel, Oiled Earth	Gravel- in county or city

Table 3-9 presents the ADT values employed in this study. Table 3-10 classifies the maintenance area and cities into urban and rural. All unpaved roads in Pinal County are considered to be rural.

Effect of Rainfall

Estimates for the average daily emissions throughout the year should reflect an adjustment for those days in which rainfall is assumed to eliminate emissions from unpaved roads. Rainfall of .01 inch or more is assumed to diminish these emissions to negligible levels. Table 3-11 shows the number of days during which .01 inch or more of rainfall occured when suspended particulate levels were being measured.* Emissions calculated for each quarter of 1975 should reflect the effect of rainfall in the quarter. Hence, average emissions from unpaved roads would be 20%

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* The rainfall adjustments were related to the periods of air quality monitoring because this permits direct air quality to emissions relationships to be established later in the study.

TABLE 3-7. SOIL SILT CONTENT OF UNPAVED ROADS IN STUDY AREA.

ROAD MAINTENANCE AREAS, MARICOPA COUNTY	AVERAGE SOIL SILT CONTENT (%)
1A	12
1B	23
1C	20
1D	23
1E	12
1F	12
2A	12
2B	23
2C	19
2D	23
2E	23
2F	23
3A	25
3B	23
3C	21
3D	27
3E	26
3F	23
3G	23
3H	23
3I	27
4A	19
4B	21
4C	23
4D	23
4E	23
4F	12
CITIES IN MARICOPA COUNTY	
Phoenix	19
Scottsdale	19
Paradise Valley	19
Glendale	23
Tempe	23
Chandler	23
Mesa	23

TABLE 3-7 (CONTINUED). SOIL SILT CONTENT OF UNPAVED ROADS IN STUDY AREA.

TOWNSHIP-RANGE, NORTH PINAL COUNTY	AVERAGE SOIL SILT CONTENT (%)
T1N, R8E	19
T1N, R9E	12
T1N, R10E	12
T1N, R11E	12
T1N, R12E	12
T1N, R13E	12
T1S, R8E	21
T1S, R9E	13
T1S, R10E	12
T1S, R11E	12
T1S, R12E	12
T1S, R13E	12
T2S, R2E	27
T2S, R8E	27
T2S, R9E	27
T2S, R10E	21
T2S, R11E	12
T2S, R12E	12
T2S, R13E	12
T3S, R2E	27
T3S, R3E	27
T3S, R4E	27
T3S, R5E	27
T3S, R6E	23
T3S, R7E	12
T3S, R8E	14
T3S, R9E	14
T3S, R10E	21
T3S, R11E	12
T3S, R12E	12
T3S, R13E	12
T4S, R2E	14
T4S, R3E	27
T4S, R4E	14
T4S, R5E	20
T4S, R6E	27
T4S, R7E	23
T4S, R8E	23
T4S, R9E	23
T4S, R10E	27
T4S, R11E	27
T4S, R12E	27
T4S, R13E	12

TABLE 3-7 (CONTINUED). SOIL SILT CONTENT OF UNPAVED ROADS IN STUDY AREA.

TOWNSHIP-RANGE, NORTH PINAL COUNTY	AVERAGE SOIL SILT CONTENT (%)
T5S, R2E	12
T5S, R3E	27
T5S, R4E	21
T5S, R5E	27
T5S, R6E	27
T5S, R7E	27
T5S, R8E	27
T5S, R9E	14
T5S, R10E	23
T5S, R11E	23
T5S, R12E	27
T5S, R13E	27
T6S, R2E	27
T6S, R3E	27
T6S, R4E	21
T6S, R5E	14
T6S, R6E	27
T6S, R7E	27
T6S, R8E	27
T6S, R9E	14
T6S, R10E	14
T6S, R11E	14
T6S, R12E	27
T6S, R13E	27

TABLE 3-8. PEDCo AVERAGE DAILY TRAFFIC VOLUMES ON UNPAVED ROADS IN PHOENIX AREA

TYPE OF ROAD	AVERAGE DAILY VEHICLE COUNT	
	URBAN	RURAL
Primitive	5	2
Unimproved	25	20
Graded and drained	75	40
Rock, gravel, oiled earth	100	60

SOURCE: Reference [2]

TABLE 3-9. TRW AVERAGE DAILY TRAFFIC VOLUMES ON UNPAVED ROADS IN PHOENIX AREA

TYPE OF ROAD	AVERAGE DAILY VEHICLE COUNT	
	URBAN	RURAL
Dirt - county maintainance	75	40
- no county maintenance	15	11
Gravel - county maintenance	100	60
Cities - dirt	75	40
- gravel	100	60

TABLE 3-10. CLASSIFICATION OF MAINTENANCE AREAS AND CITIES INTO RURAL OR URBAN

MAINTENANCE AREAS	RURAL	URBAN
1A	x	
1B	x	
1C	x	
1D	x	
1E	x	
1F	x	
2A	x	
2B		x
2C		x
2D		x
2E		x
2F		x
3A	x	
3B	x	
3C		x
3D	x	
3E	x	
3F	x	
3G	x	
3H	x	
3I		x
4A	x	
4B		x
4C	x	
4D	x	
4E	x	
4F	x	
Phoenix		x
Scottsdale		x
Paradise Valley		x
Glendale		x
Tempe		x
Chandler		x
Mesa		x

TABLE 3-11. PORTION OF AIR QUALITY SAMPLING DAYS WITH RAINFALL IN 1975.

Quarter of year	No. of days sampling particulates	No. of days with rain	Fraction of sampling days with rain
1	15	1	.06
2	15	0	.00
3	15	0	.00
4	15	3	.20
year	60	4	.06

less in the fourth quarter of 1975 than those observed in the second or third quarters.

3.1.3 Emission Estimates

The calculation of emissions is accomplished according to the procedures outlined in this section.

Maricopa County

- All emissions are calculated on the basis of each road maintenance area or city.
- Emissions from dirt and gravel roads are calculated separately.
- For gravel roads, a 12% silt content and an average speed of 35 miles/hour are assumed. The mileage of gravel roads in each maintenance area is 40% of the column labeled "County Maintenance (Adjusted)" in Table 3-4. For cities, mileage is 40% of the total miles of unpaved roads. Average daily traffic counts are either 100 vehicles/day (urban) or 60 vehicles/day (rural).
- For dirt roads, the silt content of each maintenance area or city is determined from Table 3-7. The average vehicle speed is 35 miles/hour. The mileages of dirt roads in each maintenance area are 60% of the column labeled "County Maintenance (Adjusted)" and the column labeled "No Maintenance" in Table 3-4. Dirt road mileage in cities is 60% of the total unpaved road mileages. Average daily traffic is determined from Table 3-9.

Northern Pinal County

- All emissions are calculated on the basis of individual townships and ranges .

- Emissions from dirt and gravel roads are calculated separately.
- Mileages of dirt and gravel roads in each township and range) were obtained from maps provided by the Arizona Department of Transportation.
- For gravel roads, a 12% silt content and an average vehicle speed of 35 miles/hour are assumed. All gravel roads are classified as rural and possessing an ADT of 60 vehicles/day.
- For dirt roads, the silt content of each township and range is the average of those shown in Table 3-7. Average vehicle speed is 35 miles/hour and the ADT is 40 vehicles/day (based on the assumption that all dirt roads are rural).

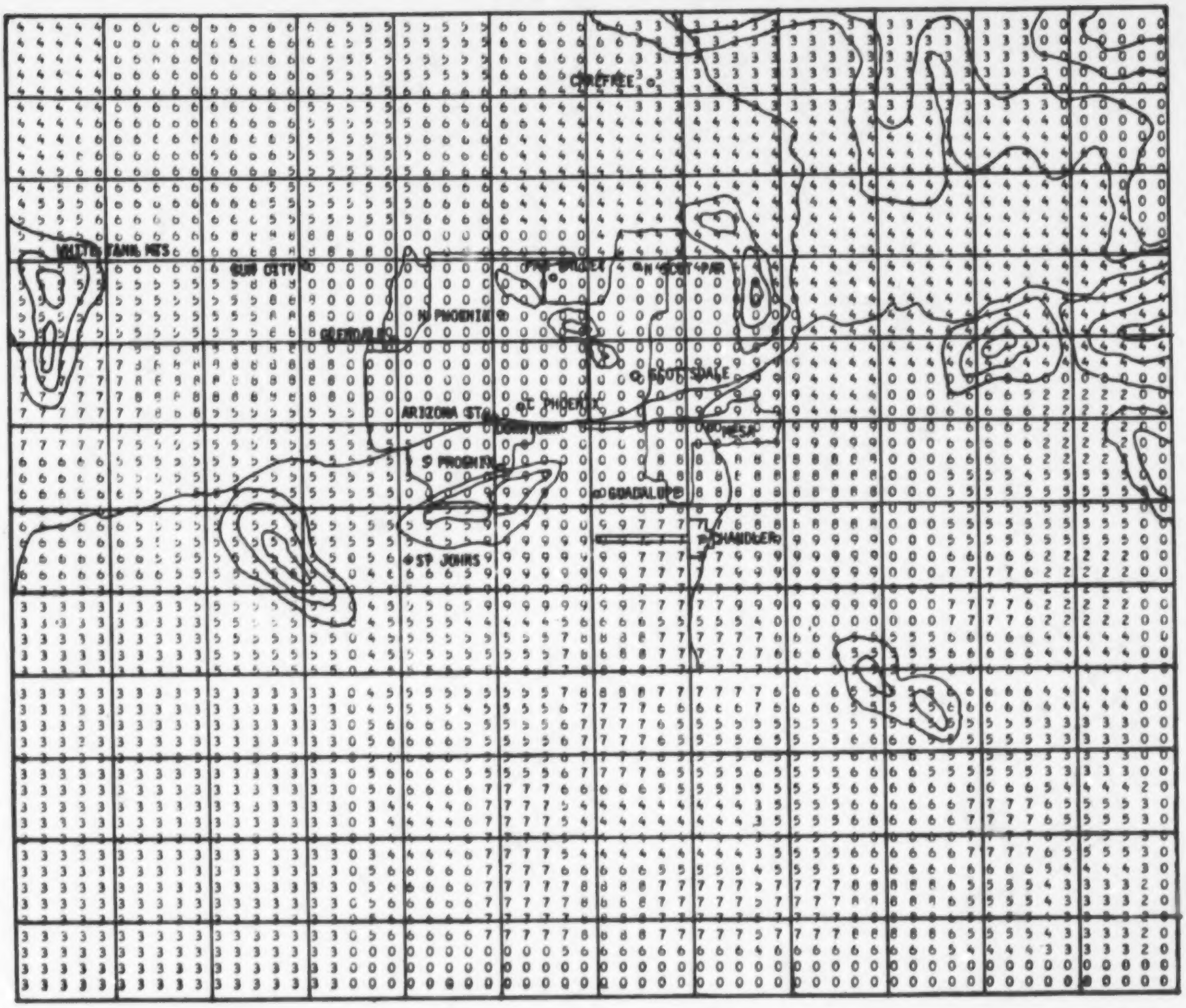
The emissions model is used to estimate average daily dust emissions from unpaved roads. For example, in Maintenance area 3A, the silt content of county-maintained dirt roads is 25% (Table 3-7), the total mileage of these roads is 93.8 (Table 3-4), the road is classified as rural (Table 3-10) with an average traffic rate of 40 light-duty vehicles per day (Table 3-9) at average speed 35 miles/hour, and during a year (1975) in which rainfall of .01 inches or more occured on 6% of the days (Table 3-11). The average daily emissions from Area 3A in 1975 are:

$$e = .81(25)(35/30)(40)(.94) = 89 \text{ lbs/day.}$$

Computer programs were developed to calculate total unpaved road emissions for each of the maintenance or township areas. An additional program was developed to translate the emissions from the maintenance and township areas into the cells of the standard emissions grid network. The calculated emissions are shown in the grid map format in Figure 3-2, and portrayed graphically in Figure 3-3. As indicated, emissions from unpaved roads are concentrated at the perimeter of metropolitan Phoenix, and a significant portion of the emissions are generated within the city areas.

The total dust emissions from unpaved roads throughout the study area in 1975 were estimated as follows:

Quarter	tons/day
1	1281
2	1365
3	1365
4	1086
Average	1281


WHITE TANK MTS
SUN CITY
CAREFREE
N SCOT PAR
N PHOENIX
GLENDALE
SCOTTSDALE
C PHOENIX
ARIZONA ST
DOWNTOWN
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 TO 0
1	0 TO .004
2	.004 TO .02
3	.02 TO .06
4	.06 TO .16
5	.16 TO .33
6	.33 TO .60
7	.60 TO 1.04
8	1.04 TO 1.67
9	1.67 TO 2.53

Figure 3-2. Grid Map for Dust Emissions from Unpaved Roads, 1975.

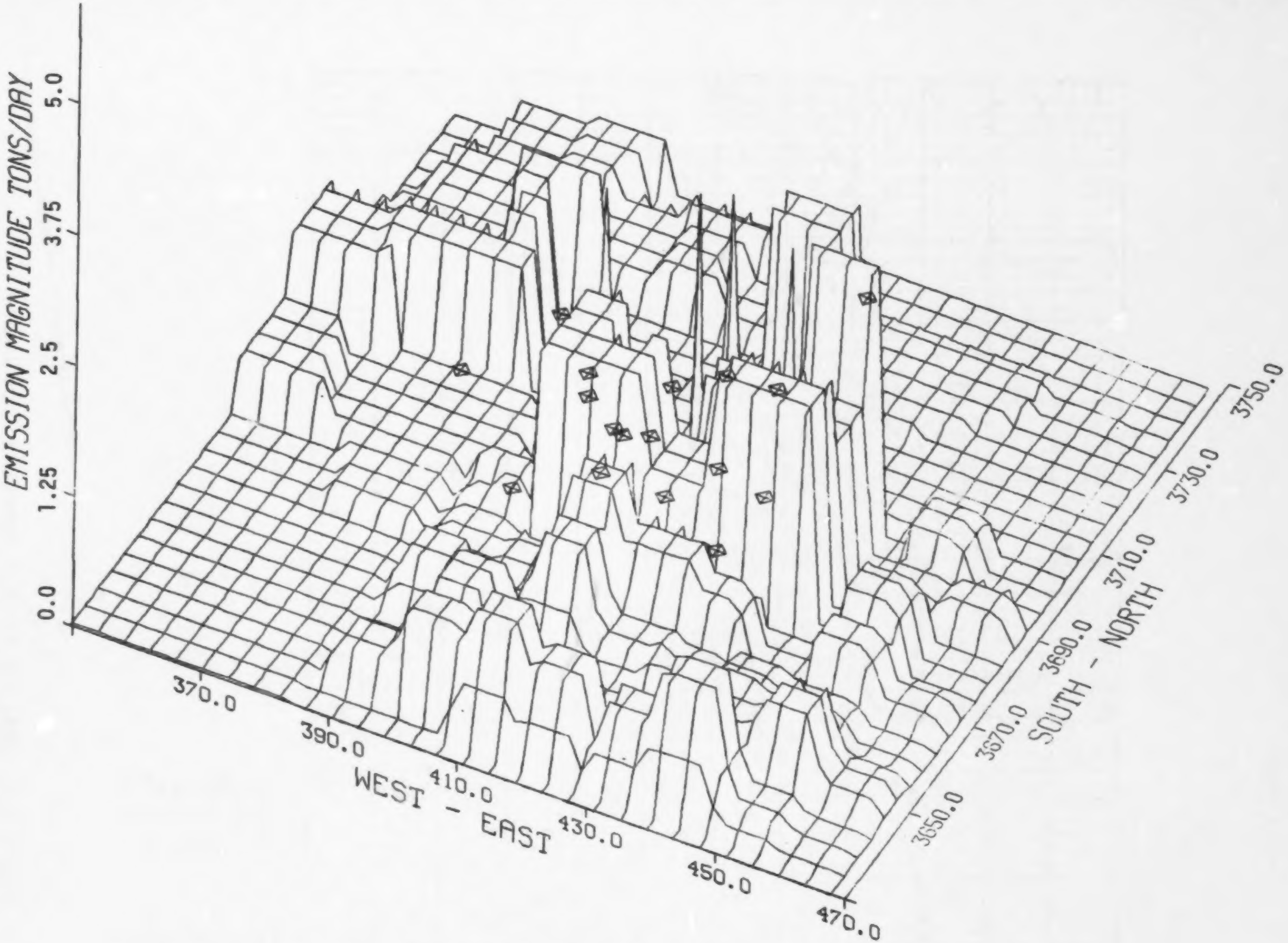


Figure 3-3. Average Daily Dust Emissions from Unpaved Roads, 1975.

Uncertainties are introduced at all levels of the emissions estimates. For example, errors are introduced in the estimates of average daily traffic (ADT), as only estimates based on previous work performed by PEDCo were available. It proved impossible to verify these ADT figures as very few vehicle counts have been made on unpaved roadways. Inaccuracies also arise with respect to mileages of unpaved roads in the study area, and the assumed distribution of road types (60% dirt and 40% gravel) in Maricopa County.

3.1.4 Particle Size Distributions

Based on field tests performed with conventional cascade impactors, the average particle size distribution of roadway emissions have been determined as shown below [1]. Due to the low capture efficiency of the impactor for larger particles, the investigators (MRI) have cautioned that these determinations are biased toward overestimation of the smaller particles.

Particle Diameter (microns)	Weight Percent
< 2	25
2 - 30	35
30 - 100	40

3.2 AGRICULTURAL TILLING OPERATIONS

This section reviews current procedures utilized to estimate fugitive dust emissions from agricultural tilling operations, and documents the methodology developed for use in the present inventory.

3.2.1 Review of Previous Inventories and Emission Factors

Emissions from agricultural activities can be expected to occur during both the planting season (when the soil is prepared by tilling) and during the harvesting season. A literature survey revealed no previous research for emissions during the harvesting process and only two studies on emissions from tilling operations (see Table 3-12).

The PEDCo emission factor was obtained from an article published in the USSR. The manner in which this emission rate was derived is unclear. The

TABLE 3-12. EMISSION FACTORS AND AGRICULTURAL TILLING OPERATIONS

SOURCE	EMISSION FACTORS	COMMENTS
PEDCo [2]	$Q = (45)(1.28)^v$ where Q = emission, grams/second v = tractor speed, location/hour	• Factor obtained from an article published in the USSR.
MRI [1]	$e = \dfrac{1.4\, s \left(\dfrac{S}{5.5}\right)}{\left(\dfrac{PE}{50}\right)^2}$ where e = emissions, lbs/acre s = silt content of surface soil, percent S = implement speed, miles/hour PE = Thornthwaite's precipitation-evaporation index	• Factor must be corrected for irrigation. • Factor derived from tests conducted with one-way disk plow and sweep-type plow, with a cut width of 12 ft. • Accuracy is ± 15%. • Applicable for particles with a drift potential >25 ft., i.e., particles <100μ in diameter.

MRI factor was the result of a test program similar to the one conducted for improved roads (see Section 3.1.1).

No previous inventories were available for agricultural tilling emissions in the Phoenix area. In developing estimates of fugitive emissions for agriculture in the Phoenix area, PEDCo concluded that only 0.2 tons/acre/year would be generated by tilling operations [2]. As this estimate resulted in emission levels considerably less than those estimated by PEDCo for cropland wind erosion, the tilling operations were neglected in their inventory.

3.2.2 Methodology of Present Inventory

The MRI factor was selected for the same reasons the MRI factor for unpaved roads was chosen in Section 3.1.2. This section will be devoted to a discussion of the parameters affecting the calculation of agricultural tilling emissions. The parameters include: (1) silt content of the soil, (2) implement speed, (3) distribution of agricultural acreage and (4) temporal distribution of tilling activities.

Two general assumptions should be mentioned. The first involves the type of implement - the MRI tests are presumed valid for one-way disk and sweep-type plows. Conversations with the Maricopa County Agricultural Agent [16] indicated that a wide variety of implements are actually employed, ranging from disk plows to moldboard plows to listers. It is assumed emissions do not differ greatly from one implement type to another. Secondly, it is presumed that no irrigation is conducted before plowing. This was substantiated by the County Agricultural Agent [16]. It should be noted that most fields are flooded with 9" to 12" of water after plowing to leach out salts from the previous season.

Distribution of Agricultural Acreage

The spatial distribution of agricultural acreage within the study area was obtained from the "Cropland Atlas of Arizona" [17]. This publication illustrates the location and shape of agricultural fields for the entire state as they appear from high altitude. Flights were conducted by the National Aeronautics and Space Administration from May 1972 to October 1973. Although this period does not correspond to the baseyear of this study

(1975), the distribution of all crop acreage has not changed substantially during the intervening years [16].

The agricultural acreage within each township was estimated by scaling the aerial maps of the cropland Atlas. A check procedure was employed for Maricopa County to compare the published agricultural acreage (Reference [18]) versus the estimated acreages. The total of the estimated acreage of all townships was found to be only 8% less than the published figures.

Soil Silt Content

Silt content is defined to be the weight percent of the top four inches of soil having particle diameter from 2 to 50 microns (.002 mm to .05mm). The procedure employed to determine silt content for cropland of a given townwhip is as follows:

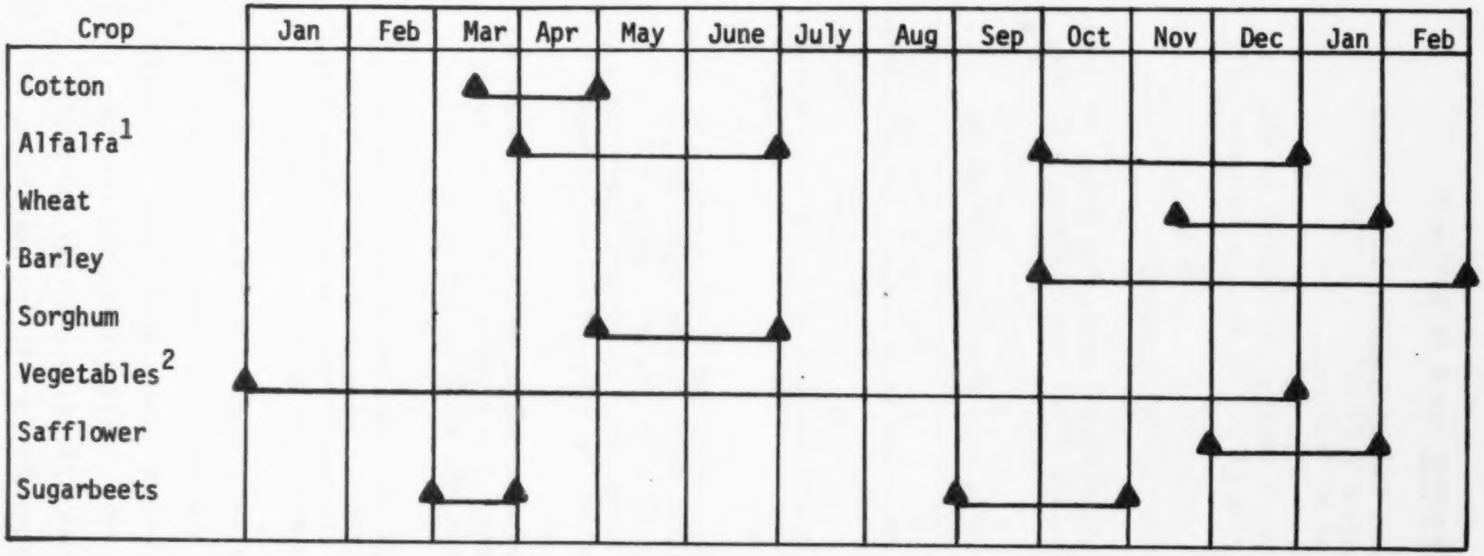
- In any given township, the predominant soil type in the area where crops are grown is assumed to be the soil types for all agricultural acreage in that township. Soil type distributions were found in References [11] and [19].
- For soil types which surface silt content was available (Reference [13], these figures were employed. Otherwise, silt content of a deep core sample (generally 0 to 5 feet in depth) as described in Reference [12] were used. In all cases, a range of silt contents is available.

Implement Speed

Limited data are available to characterize typical speeds of tillage implements [1]. Investigation during the present study confirmed previous findings that a speed of 5 miles/hour is generally representative of most tilling operations [16].

Temporal Distribution of Emissions

Tilling operations are conducted once anually and in a given season depending on the crop type. Emissions were calculated on a temporal basis to demonstrate this variation. Figure 3-4 illustrates the usual planting periods for the major crops in Maricopa and Pinal Counties (citrus fruits are not included, as they are not planted yearly).



Source: Reference (18)

[1] Alfalfa is planted and then cut for three years. Planting is usually during Fall and Spring.

[2] Vegetables include broccoli, cabbage, carrots, cauliflower, lettuce and onions. These vegetables are planted at different times during the year (i.e. cabbage from Aug. 1-March 15, onions from Oct. 12-Dec. 5) but span the entire year. For the purposes of this study, vegetables are assumed to be planted all-year around.

Figure 3-4. Typical Planting Dates in Arizona

3.2.3 Emission Estimates

All emissions are calculated on a township basis as follows:

(1) The fraction of each township used for agriculture is obtained from Reference [17]. The percentage multiplied by 23,040 acres/township yields the acreage of farmland.

(2) The silt content of the agricultural acreage calculated in Step (1) is available in References [12] and [13]. An average value of silt is employed.

(3) The average speed of the implement is 5 miles/hour.

(4) The historical Thornthwaite Precipitation-Evaporation Index for irrigated agricultural lands in the study area is approximately 50 (see Section 4.3).

(5) The emission (lbs/acre) can be calculated from the information obtained in Steps (2), (3) and (4).

(6) The total agricultural tilling emissions in a township are calculated from the result of steps (1) and (5).

The following sequence of steps describes how the emissions are distributed within any township on a temporal basis:

(7) Table 3-13 illustrates the percentage of the total acreages in Maricopa and Pinal Counties devoted to each crop type. Only crops requiring tilling (i.e., excluding citrus crops) are considered. These percentages are assumed to be applicable for each township, e.g., 35% of each township in Maricopa County is used to grow cotton.

(8) Emissions from one crop type are distributed temporally only during the planting season for that crop. For example, all cotton related tilling emissions occur only from mid-March to the end of April (see Figure 3-4).

(9) Table 3-14 presents the temporal distribution of tilling emissions by crop type. For cotton cropland in Maricopa County, 1/3 x 35% = 11.6% and 2/3 x 35% = 23.4% of the annual study area tilling emissions occur on cotton fields in March and April respectively.

Tilling emissions vary substantially by season. The greatest tilling activity occurs in the second quarter of the year, when about 30 tons/day of fugitive dust are generated. Tilling on cotton fields contributes the major portion of dust emissions during this period. Tilling emissions average only 1 ton/day during the third quarter, when planting activity for most crops is minimal. The total emissions inventory for tilling operations in

TABLE 3-13. CROP ACREAGE DISTRIBUTIONS IN MARICOPA AND PINAL COUNTIES [18]

County	Crop[1]	1974 Acreage	Percent of Total Acreage
Maricopa	Cotton	166,100	35
	Alfalfa	106,900	23
	Wheat	74,000	16
	Barley	50,000	11
	Sorghum	32,000	7
	Vegetables[2]	25,410	5
	Safflower	7,700	2
	Sugarbeets	4,670	1
		472,580	100
Pinal	Cotton	141,950	50
	Wheat	56,000	20
	Barley	38,000	13
	Alfalfa	18,900	7
	Sorghum	14,000	5
	Safflower	6,800	2
	Sugarbeets	4,670	2
	Vegetables	4,380	1
		284,700	100

[1] Does not include citrus crops and miscellaneous fruits, vegetables and field crops.

[2] Includes broccoli, cabbage, carrots, cauliflower, lettuce and dry onions.

TABLE 3-16. TEMPORAL DISTRIBUTION OF TILLING EMISSIONS IN MARICOPA AND PINAL COUNTIES

County	Crop	Percent of Total County Emissions	Percent Distribution of Crop Type Emissions by Month											
			J	F	M	A	M	J	J	A	S	O	N	D
Maricopa	Cotton	35			11.6	23.4								
	Alfalfa	23				1.27*	1.27*	1.27*				1.27*	1.27*	1.27*
	Wheat	16	5.4										3.2	5.4
	Barley	11	2.2	2.2								2.2	2.2	2.2
	Sorghum	7					3.5	3.5						
	Vegetables	5	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	Safflower	2	1											1
	Sugarbeets	1			0.33						0.33	0.33		
Pinal	Cotton	50			16.1	33.4								
	Wheat	20	8										4	8
	Barley	13	2.6	2.6								2.6	2.6	2.6
	Alfalfa	7				0.39*	0.39*	0.39*				0.39*	0.39*	0.39*
	Sorghum	5					2.5	2.5						
	Safflower	2	1											1
	Sugarbeets	2			0.67						0.67	0.67		
	Vegetables	1	.083	.083	.083	.083	.083	.083	.083	.083	.083	.083	.083	.083

*Alfalfa is planted once each three years. These percentages are thus 1/3 of emissions from tilling operations.

the second quarter is shown in grid map format in Figure 3-5, and graphically in Figure 3-6. As indicated, the greatest agricultural activity occurs at the Northwest and Southeast boundaries of metropolitan Phoenix.

3.2.4 Particle Size Distributions

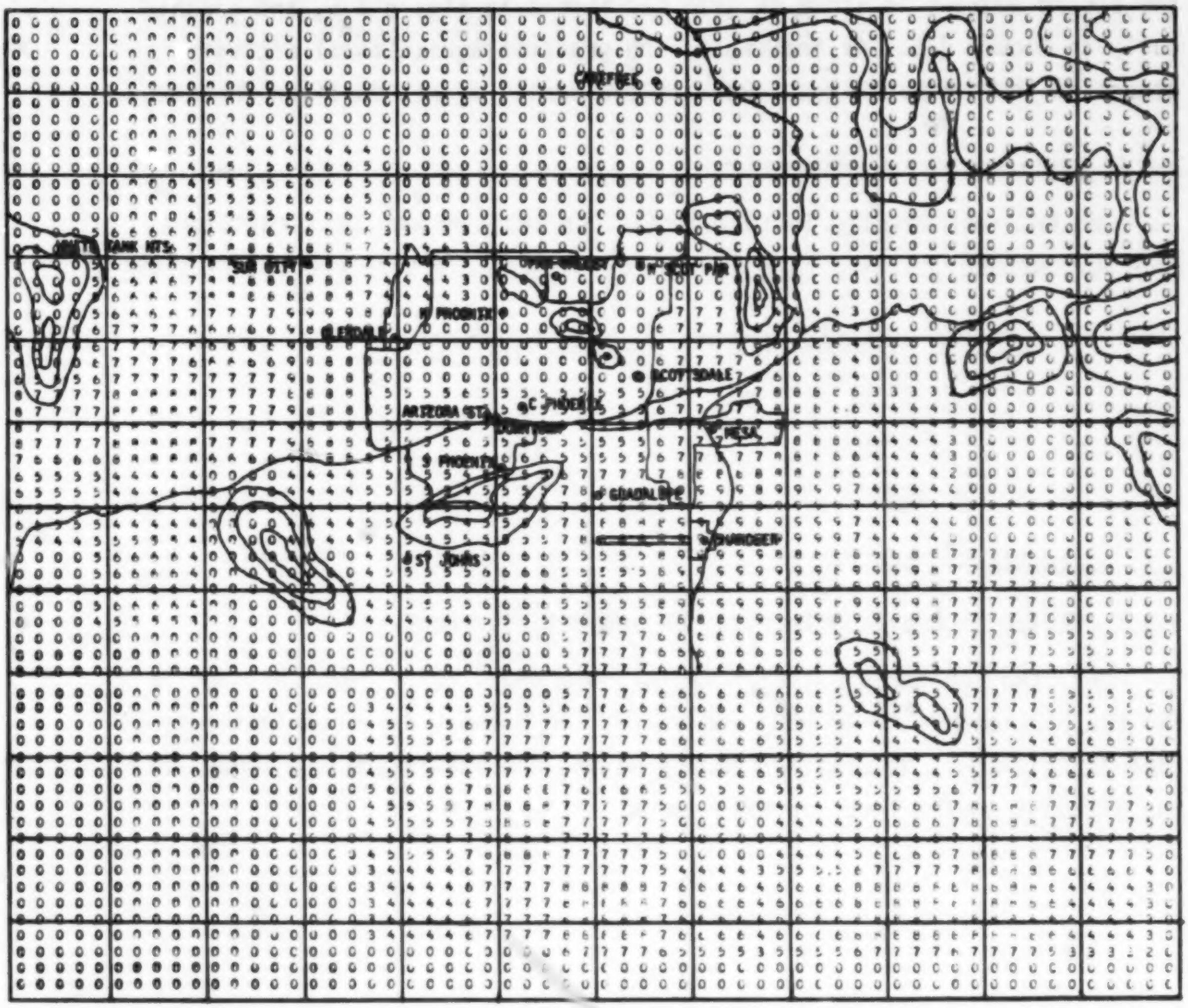
The MRI test results indicated that, on the average, dust emissions from agricultural tilling have the following particle size characteristics:

Particle Diameter (microns)	Weight Percent
< 2	35
2 - 30	45
> 30	20

3.3 AGGREGATE STORAGE PILES

3.3.1 Review of Previous Inventories and Emission Factors

Only two published emission factors are known to be reported, one in the EPA Publication AP-42 [20] and one by the Midwest Research Institute [1] (see Table 3-15). No details concerning the EPA derivation are known, so the discussion will focus on MRI's work.


CAREFREE
WHITE TANK MTS.
SUN CITY
N PHOENIX
GLENDALE
SCOTTSDALE
ARIZONA ST
C PHOENIX
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00000
1	.00000 TO .00011
2	.00011 TO .00057
3	.00057 TO .00180
4	.00180 TO .00440
5	.00440 TO .00913
6	.00913 TO .01692
7	.01692 TO .02886
8	.02886 TO .04622
9	.04622 TO .0704

Figure 3-5. Grid Map for Dust Emissions from Agricultural Tilling, Second Quarter, 1975.

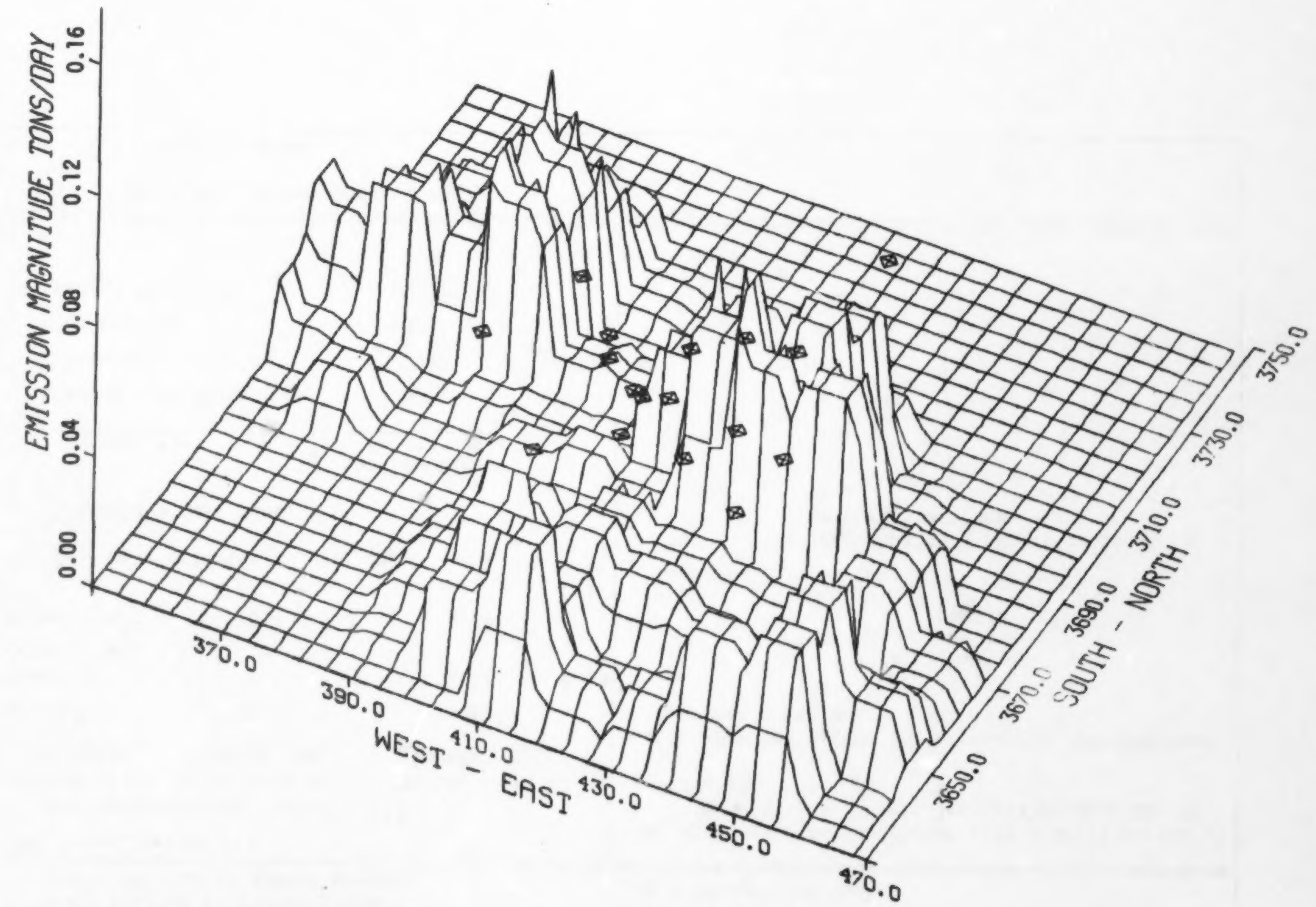


Figure 3-6. Average Daily Dust Emissions from Agricultural Tilling Operations, Second Quarter, 1975.

TABLE 3-15. EMISSION FACTORS FOR AGGREGATE STORAGE PILES

<table>
<tr><th>Emission Factor</th><th>Comments</th></tr>
<tr><td>EPA Document AP-42 [20]:
e = 2 lbs/ton of stored product
e = 10 lbs/ton of stored product</td><td>● Screening, conveying and handling losses
● Storage pile losses</td></tr>
<tr><td>MRI Investigation [1]:
Aggregate Storage Operation (1)
<table>
<tr><th>Storage Pile Activity</th><th>Lbs/acre of Storage/day</th><th>Lbs/ton placed in storage</th></tr>
<tr><td>Active[a]</td><td>13.2</td><td>0.42</td></tr>
<tr><td>Inactive (wind blown)</td><td>3.5</td><td>0.11</td></tr>
<tr><td>Normal mix[b,c]</td><td>10.4</td><td>0.33</td></tr>
</table>
[a] 8-12 hour activity/24 hour day
[b,c] 5 active days/week
<table>
<tr><th>Normal Mix</th><th>Lbs/ton placed in storage</th></tr>
<tr><td>Loading onto piles</td><td>0.04</td></tr>
<tr><td>Vehicular traffic</td><td>0.13</td></tr>
<tr><td>Wind erosion</td><td>0.11</td></tr>
<tr><td>Loadout from piles</td><td>0.05</td></tr>
<tr><td></td><td>0.33</td></tr>
</table>
</td><td>● Applicable for particles with a drift potential >1000 ft, i.e., particles smaller than 30μ in diameter
● Correction factor for normal mix for different climatic regions:
$$e = \frac{0.33}{\left(\frac{PE}{100}\right)^2}$$
where
PE = Thornthwaite's precipitation-evaporation index</td></tr>
<tr><td>Aggregate Loadout Operation (2)
e = 0.11 lbs/ton loaded</td><td></td></tr>
</table>

MRI conducted two field sampling programs. The first was designed to quantify total dust emissions from the various constituent sources associated with a representative aggregate storage operation, while the second attempted to quantify emissions from a specific storage transfer operation - aggregate loadout.

Conventional Hi-Vol samplers with wind direction activators were employed in the first study because of the diffuse and variable nature of the source. Four influence factors - rainfall, wind speed, type of aggregate and amount of activity in the piles - were considered. Only two, rainfall and amount of activity, were found to affect emissions. Emission factors were calculated by assuming that all emissions from the stockpiles passed through an imaginary vertical plane with the dimensions of the width of the storage area by the average height of the piles; that the samplers located downwind of the piles sampled particulate concentrations representative of average particulate concentrations passing through this vertical cross section; and that the total air volume containing this average concentration could be approximated as the average wind speed times the area of the cross section. Calculations were performed for two conditions, active piles and inactive piles, and included contributions from the movement of traffic among the storage piles and from loading and unloading operations, plus wind erosion. The factors do not include emissions from the mining or processing of the aggregate or from traffic movement in other parts of the plant. MRI cautions that the factors are not universally applicable and are intended to be representative for storage piles in areas of the country with climatic conditions similar to Cincinnati, Ohio. For normal mix operations (see Table 3-15), a correction factor for different climatic conditions is given.

Field measurements were also made during the aggregate loadout program. Conventional Hi-Vol and cascade impactors were the instrumentation. A high-loader and dump truck were the "test vehicles." Total dust emissions were the sum of the integrated exposure (above the background) and the amount of deposition between the back of the truck and the exposure profiler. Results of the program are shown in Table 3-15.

A previous inventory of aggregate pile emissions was performed for the Phoenix-Tucson AQCR by PEDCo. Emissions were estimated utilizing the EPA emissions factor and by obtaining storage pile data through existing emission source files at county and state air pollution control agencies.

3.3.2 Methodology of the Present Inventory.

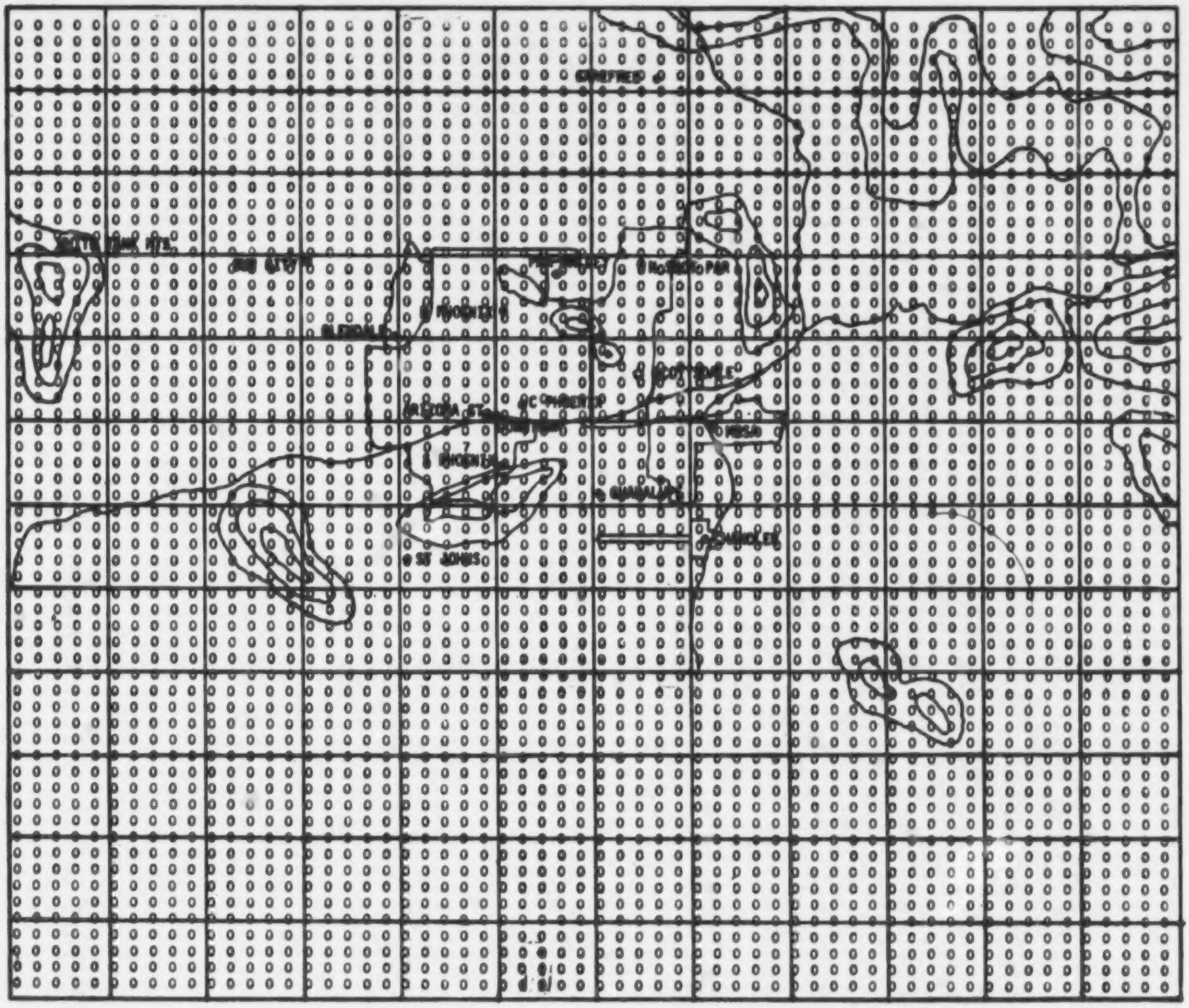
The MRI "normal mix" emission factor, adjusted to the historical PE Index for Phoenix (see Section 4.2), was selected. Accordingly, an emission factor of 36.6 lbs/ton of aggregate storage was calculated. The locations and storage rates of aggregate piles were obtained from the most recently available NEDS point source listing. Based on an average of approximately 1100 tons of aggregate pile material stored throughout the study area, total dust emissions arising from these atorage piles is estimated to be relatively insignificant-- just .01 tons/day. Figures 3-7 and 3-8 illustrate the grid map and distribution of aggregate pile emissions for the study area.

3.3.3 Particle Size Distributions

MRI did not conduct a particle size distribution measurement program for the "normal mix" emission factor. However, such a program was carried out for the aggregate loadout emission factor. The loadout size distributions were assumed to be representative for the normal mix emissions. This distribution is as follows:

Particle Size (μ)	Weight Percent
1	30
1 - 2	46
2 - 3	16
3 - 4	6
4	4

Three major sources of uncertainties are associated with this data: (1) the sampling technique is biased towards the smaller diameters, (2) aggregate loadout emissions comprise only 1/3 of the total "normal mix" emissions (see Table 3-15) and (3) the characteristics of aggregate as tested by MRI may not be similar to those in Arizona.


CAREFREE
WHITE TANK MTS.
SUN CITY
GLENDALE
PHOENIX
SCOTTSDALE
ARIZONA ST.
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00000
1	.00000 TO .00004
2	.00004 TO .00023
3	.00023 TO .00072
4	.00072 TO .00175
5	.00175 TO .00363
6	.00363 TO .00672
7	.00672 TO .01147
8	.01147 TO .01837
9	.01837 TO .02800

Figure 3-7. Grid Map for Dust Emissions from Aggregate Piles, 1975.

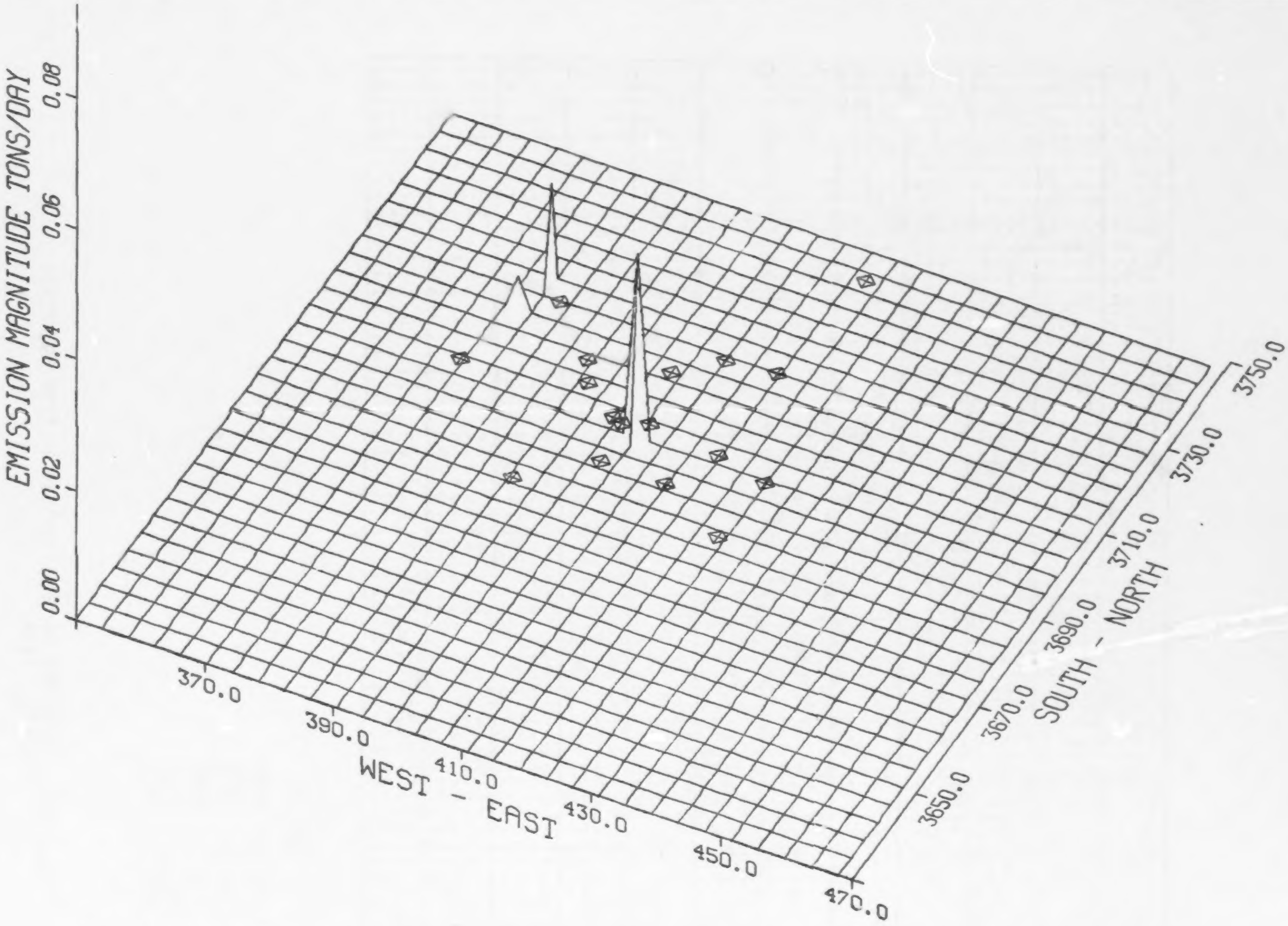


Figure 3-8. Average Daily Dust Emissions from Aggregate Piles, 1975.

3.4 CATTLE FEEDLOTS

3.4.1 Review of Previous Inventories and Emission Factors

PEDCo was found to have developed the only emission factor for cattle feedlots (see Table 3-16). The development involved ambient air measurements during two 24-hour periods at 24 California feedlots. The feedlot emission factor was derived by relating ambient air data to emission rates utilizing the Pasquill-Gifford diffusion equation [14]. Concurrent wind data for the tests was not available, hence, mean local annual wind speeds and a D stability class were assumed. Thus, PEDCo concluded that the calculated average values could be inaccurate by a factor of 2. The emission factor is expressed in terms of tons per thousand head cattle or as tons per acre of feedlot.

The only emission inventory performed for cattle feedlots in the Study Area was also conducted by PEDCo [2]. Feedlots containing more than 5000 head only were considered. The names and sizes of individual lots were obtained by a telephone survey of names shown in local agency files or in the telephone directory. The totals from this survey were balanced against published data in county agricultural statistical reports.

3.4.2 Methodology of the Present Inventory

The Maricopa County Agricultural Agent [16] was contacted to determine the size and locations of major cattle feedlots (greater than 5000 head/feedlot) in Maricopa and northern Pinal Counties. These are presented in Table 3-17. By applying the emission factors shown in Table 3-16, total average feedlot emissions were calculated to be 6.5 tons/day in the study area. Figures 3-9 and 3-10 illustrate the emission distributions for the study area.

3.4.3 Particle Size Distributions

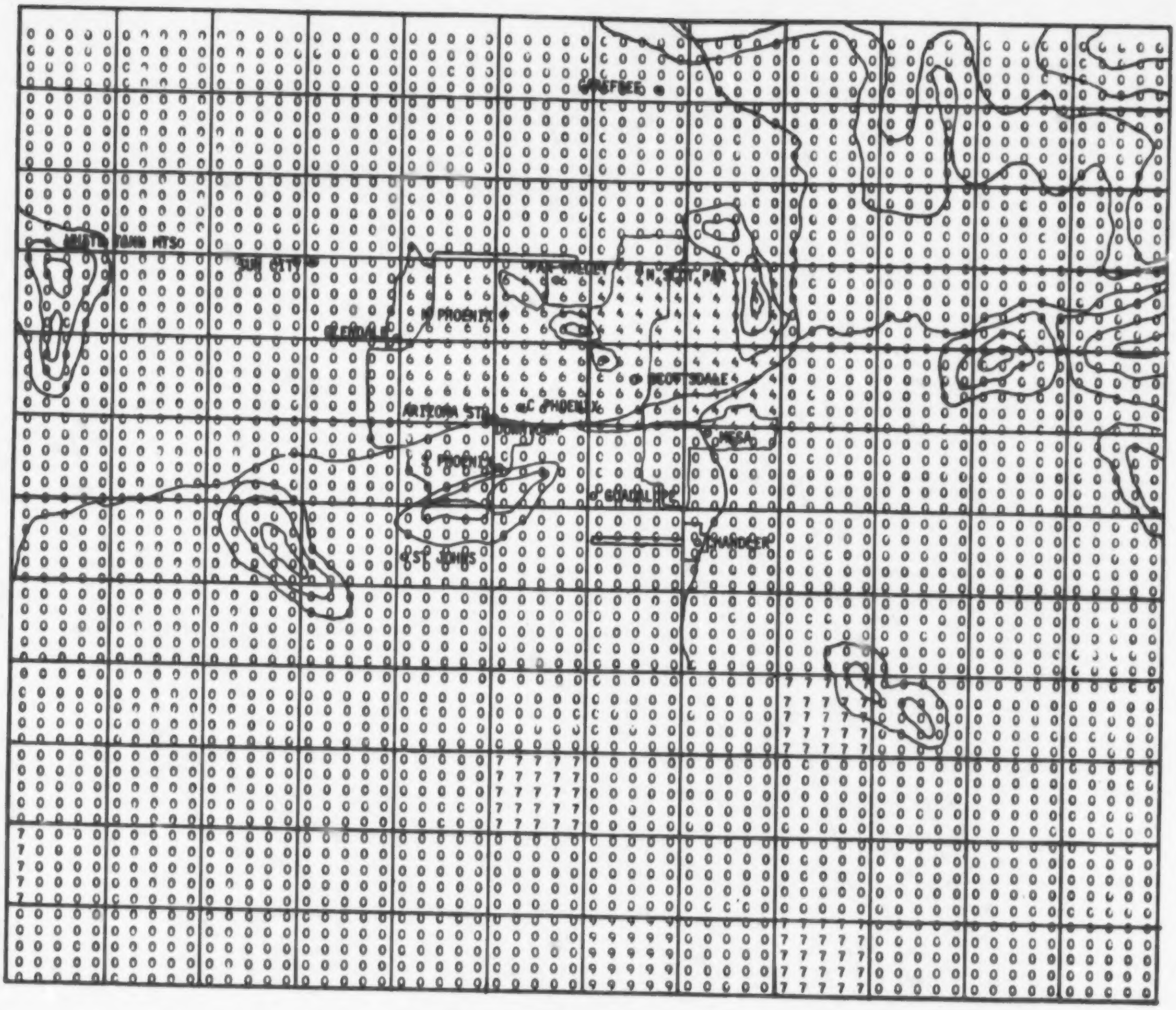
Particle sizes of cattle feedlot dust emissions are not reported in the literature. Because of the continual pulverization of the feedlot soil by cattle, the dust arising from this activity was assumed to approximate the size distributions of dust emissions off dirt roads.

TABLE 3-16. EMISSION FACTORS FOR CATTLE FEEDLOTS

Cattle, 1000 head		Size of Feedlots acres		Annual Emissions	Annual Emissions
Range	Average	Range	Average	tons/10^3 heads	tons/acre
<3	2	<20	5	8	3
3-30	9	10-100	20	8	4
>30	45	>60	90	5	3

TABLE 3-17. CATTLE FEEDLOTS IN THE STUDY AREA

County	Feedlot and Address	Size (10^3 Head)
Maricopa	Rogers Feedlot - Baseline and 51st Avenue	8
	Herseth Feed Co. - 35th Ave and Southern	30
	Hughes-Garry Co. - Queen Creek Rd.	55
	Scottsfield Feeding Co. - Scottsdale	11
	Willis Feed Co. - McQueen Rd and Germaine	4
	Arlington Cattle Co. - Arlington	30
	Gila Feed Yard - Gila Bend	40
	Producers Livestock - Washington St.	15
Pinal	Spur Industries - Sacaton	30
	Red River Feeding Co. - Stanfield	125
	Benedict Feed Co., - Stanfield	20
	Kelly Feeding Co. - Maricopa	5
	T & C Feeding - Maricopa	25
	West Coast Cattle Co. - Casa Grande	30



CAREFREE
WHITE TANK MTS
SUN CITY
PAR VALLEY
N. SCOT. PAR
N PHOENIX
GLENDALE
SCOTTSDALE
ARIZONA STA
C PHOENIX
DOWNTOWN
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST. JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00000
1	.00000 TO .00014
2	.00014 TO .00070
3	.00070 TO .00220
4	.00220 TO .00537
5	.00537 TO .01115
6	.01115 TO .02065
7	.02065 TO .03523
8	.03523 TO .05642
9	.05642 TO .08600

Figure 3-9. Grid Map for Dust Emissions from Cattle Feedlots, 1975.

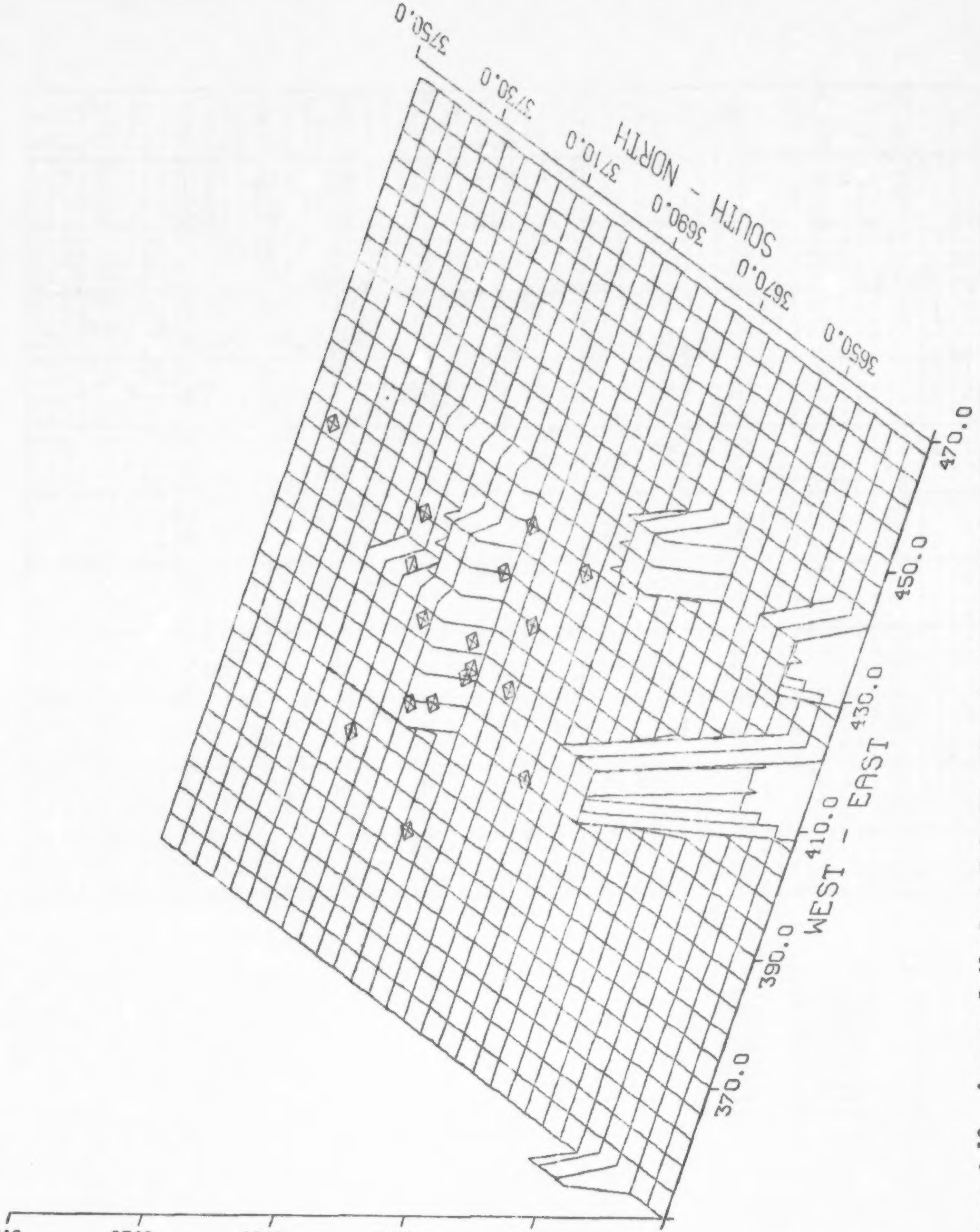


Figure 3-10. Average Daily Dust Emissions from Cattle Feedlots, 1975.

3.5 OFF-ROAD MOTOR VEHICLES

In the context of this study, off-road vehicles are defined to include both motor vehicles and motorcycles. Generally, the motor vehicles possess four-wheel drive and the motorcycles are of the two-stroke variety.

Very little data is available to determine the frequencies and locations of off-road vehicle use. The activity is recreational in nature and subject to unpredictable variations. The information presented here is based on crude estimates obtained from cognizant individuals familiar with off-road vehicle use.

3.5.1 Motorcycles

Over 95% of the dirt bike activity occurs within a 100 mile range of the metropolitan Phoenix area. The most popular areas are in the hills and mountains to the north and east of the metropolitan areas, where 3000 - 4000 riders may be found during weekends [21, 26]. On weekdays, the activity drops into the hundreds. Typical of the riding activity in these locations is cross country biking, with the Cavecreek and Usery Mountain areas as locations of where this activity originates. Other areas include Apache Junction in Pinal County, Buckeye, Lake Pleasant and the Four Peaks area in Maricopa County [21,22,23,24,25,26]. The city of Phoenix has set aside 270 acres northeast of the town of Catcus for dirt riding. In that area, weekends draw about 75 bikers/day and weekdays about 10/day [23].

Bureau of Land Management property is widely and indiscriminately used by bikers. Most commonly used are the ground surfaces readily accessible from roadways, where there is a lack of development and where there are no indications of BLM supervision [22]. Maricopa County has a no-riding policy which apparently cannot be enforced. Both the U.S. Forest Service and BLM are contemplating the closure of certain areas, but definite action has yet to be taken [21,22].

Dirt biking is a year-around activity in the Phoenix area. The bikers generally stay on site for 3 - 5 hours and travel at speeds not exceeding 30 miles/hour.

Emission Factor

The MRI emissions model [1] for motor vehicles on unpaved roads was adopted for use. Consultation with MRI [10] indicated that the factor should be adjusted downwards by 25% to 50% due to both the number of wheels and aerodynamic characteristics of motorcycles versus motor vehicles. The decision was made to employ a 50% reduction.

Location and Level of Activity

Based on an average of 3500 total cycles operating per weekend in the designated areas, the townships within the study area may be determined. The assigned activity levels are shown, township by township, in Table 3-18. Weekday activity is assumed to be about one seventh that for a weekend day.

Average daily travel per cycle is assumed to be about 45 miles based on 3 hours of riding at approximately 15 miles/hour.

Vehicle Speed

An average speed of 15 miles/hour is assumed.

Soil Silt Content

The silt content of the townships presented in Table 3-19 are determined from References [11] and [19], utilizing the same procedure as was applied for agricultural fields (Section 3.2.2).

Emission Estimates

Table 3-20 illustrates the results of the emissions calculations. The emissions are calculated both for the weekend period, when the substantial portion of off-road travel is conducted, and for the weekdays, when off-road activity is relatively minimal. The average daily emission rate for off-road cycle travel is calculated to be 54.2 tons/day.

TABLE 3-18. LOCATIONS AND LEVELS OF OFF-ROAD MOTORCYCLE ACTIVITY

Township and Range	Cycles/Weekend	Cycles/Weekday[a]
T1S, R3W	150	11
T1N, R8E	300	21
T2N, R6E	150	11
, R7E	150	11
, R8E	150	11
T3N, R1E	300	21
T4N, R5E	75	6
, R7E	150	11
, R8E	150	11
, R10E	300	21
T6N, R1W	150	11
, R1E	150	11
, R4E	80	6
, R5E	80	6
, R6E	80	6
, R7E	80	6

[a] Weekday activity is assumed to be one seventh the level of weekend day activity.

TABLE 3-19. SOIL SILT CONTENTS FOR OFF-ROAD MOTORCYCLE ACTIVITY

Township and Range	Soil Silt Content (percent)
T1S, R3W	20-60
T1N, R8E	5-30
T2N, R6E	10-30
, R7E	10-30
, R8E	10-30
T3N, R1E	30-50
T4N, R5E	10-30
, R7E	20-60
, R8E	10-30
, R10E	10-30
T6N, R1W	10-30
, R1E	20-60
, R4E	10-30
, R5E	10-30
, R6E	10-30
, R7E	10-30

TABLE 3-20. EMISSIONS FROM OFF-ROAD MOTORCYCLES

Township and Range	Average Silt Content (%)	Emission Rate (Lb/Veh-Mile)	Cycles Per Weekend	Emissions tons/weekend	Emissions tons/weekday
T1S, R3W	40	8.1	150	27.3	2.0
T1N, R8E	17	3.4	300	22.9	1.6
T2N, R6E	20	4.1	150	13.8	1.0
, R7E	20	4.1	150	13.8	1.0
, R8E	20	4.1	150	13.8	1.0
T3N, R1E	40	8.1	300	54.6	3.9
T4N, R5E	20	4.1	75	6.9	.5
, R7E	40	8.1	150	27.3	2.0
, R8E	20	4.1	150	13.8	1.0
, R10E	20	4.1	300	27.7	1.9
T6N, R1W	20	4.1	150	13.8	1.0
, R1E	40	8.1	150	13.8	1.0
, R4E	20	4.1	80	7.4	.5
, R5E	20	4.1	80	7.4	.5
, R6E	20	4.1	80	7.4	.5
, R7E	20	4.1	80	7.4	.5
				279.1	19.9

NOTE: Average motorcycle speed is 15 miles/hour
Average mileage/cycle is 45

3.5.2 Motor Vehicles

Because of their relatively limited mobility (as compared to dirt bikes), the activities of four-wheel drive vehicles were discovered to be of lesser scope than motorcycles. However, data on the frequency and total number of vehicles were sadly lacking. Only the organized functions of the major off-road vehicle club in the area, the Phoenix 4-Wheel Club, could be documented. Activities of private parties, such as hunters and occasional weekend vacationers, could not be quantified. As a result, the estimates made in this report are probably less than the actual levels.

According to the Phoenix 4-Wheel Club [27], three locations in Maricopa and Northern Pinal Counties are preferred - the Sycamore Canyon in the Tonto National Forest, the P-4 W Ranch* outside of Wickensburg and an area near Florence (in Pinal County). Normally, the Club conducts one organized trip/month, consisting of approximately 13 vehicles and having an average trip length of 150 miles. Occuring more frequently are impromptu trips arranged by individuals in the Club.

Emission Factor

The MRI Emissions Model [1] for vehicles on unpaved roads was selected for use. Discussions with MRI [10] resulted in the decision that no adjustment was required.

Location and Level of Activity

The location of off-road motor vehicle activity is described on a township basis as shown in Table 3-21. An average weekend traffic level of 13 vehicles per location is assumed, as well as an average trip length of 150 miles. The average speed is assumed to be 30 miles/hour. Weekday traffic activity is assumed to be one seventh the level of a weekend day.

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* The Bureau of Land Management has given the Phoenix 4-Wheel Club (P-4W) a special permit to use this area.

TABLE 3-21. LOCATION OF OFF-ROAD FOUR WHEEL VEHICLE ACTIVITY

Township and Range
T7N, R4W
T4N, R7E
T4S, R10E

Soil Silt Content

The silt content of the affected townships is presented in Table 3-22 and are determined from References [11] and [19], utilizing the same procedure as detailed for agricultural fields (see Section 3.2.2).

Emission Estimates

Table 3-23 presents the emission estimates for off-road four wheel vehicle travel. The emissions are calculated for the weekend period, when the major portion of off-road travel is conducted, as well as for weekdays, when travel activity is minimal. The average daily emission rate for off-road four wheel vehicle travel is calculated to be 16.8 tons/day.

The total average dust emissions associated with both off-road cycle and four wheel vehicle activity is 71 tons/day. Weekday emissions are only one seventh that occuring on weekend days. Figure 3-11 shows the distribution of emissions in the grid format, and Figure 3-12 portrays the distribution graphically. As indicated, dust emissions from off-road vehicles are generally concentrated in remote areas outside of Metropolitan Phoenix. The uncertainty associated with the estimates of both the magnitude and location of the emissions is substantial.

3.5.3 Particle Size Distributions

It is assumed that the size distribution of emissions from off-road motor vehicles will be the same as for vehicles on unpaved roads:

Particle Size (μ)	Weight Percent
< 2	25
2 - 30	35
30 - 100	40

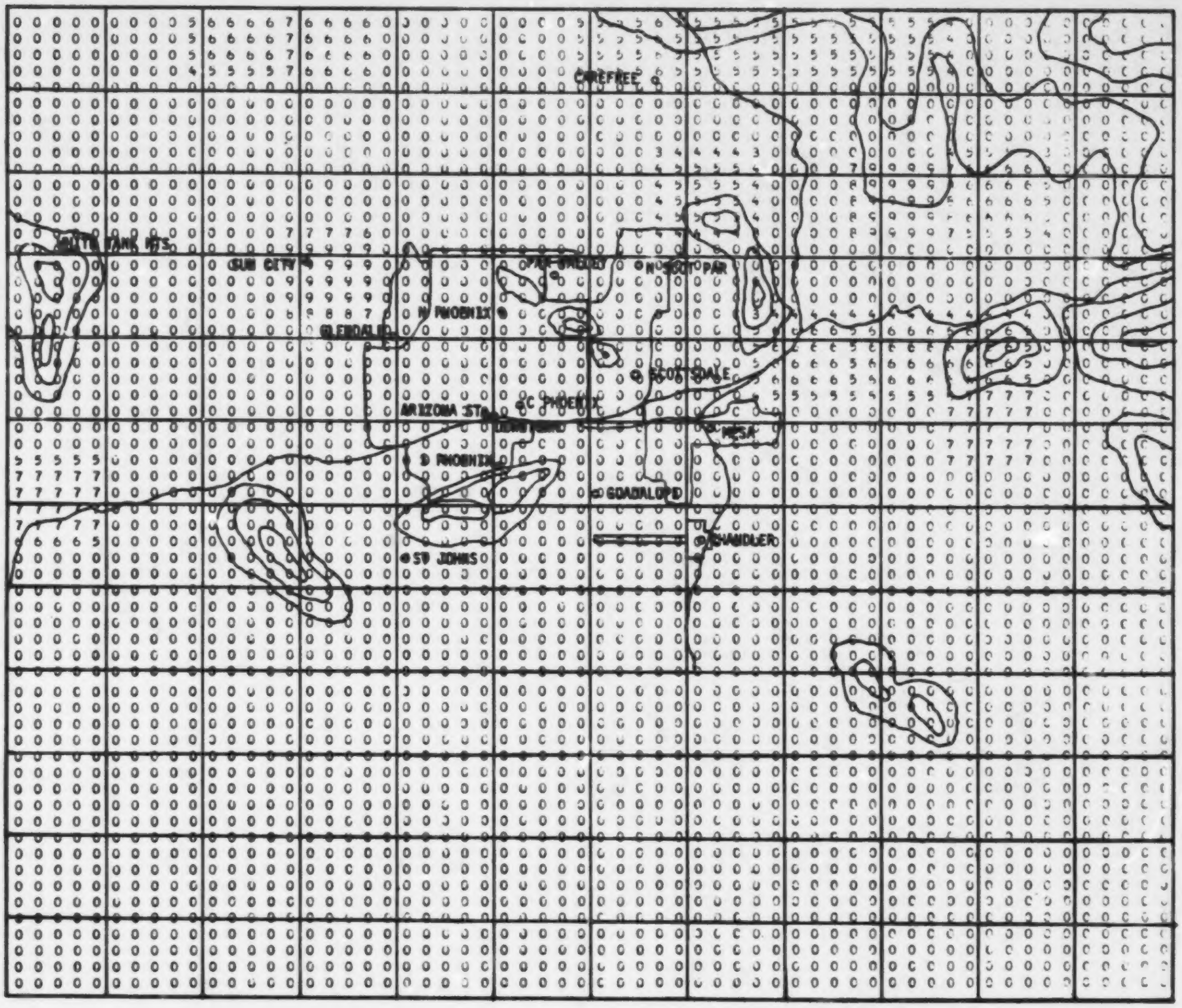
TABLE 3-22. SOIL SILT CONTENT IN AREAS OF OFF-ROAD FOUR WHEEL VEHICLE ACTIVITY

Township and Range	Soil Silt Content (%)
T7N, R4W	10-30
T4N, R7E	20-60
T4S, R10E	30-70

TABLE 3-23. EMISSIONS FROM OFF-ROAD FOUR WHEEL VEHICLES

Township and Range	Average Silt Content (%)	Emission Rate (Lb/Veh-Mile)	Emissions (Tons/Weekend)
T7N, R4W	20	16.2	15.8
T4N, R7E	40	32.4	31.59
T4S, R10E	50	40.5	39.48
			86.9

Note: Average vehicle speed is 30 miles/hour, activity is 13 vehicles /day per township, and average trip length is 150 miles.


CAREFREE
WHITE TANK MTS.
SUN CITY
GLENDALE
N PHOENIX
N SCOT PAR
SCOTTSDALE
C PHOENIX
ARIZONA ST
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY		
0	0.00000	TO	.00000
1	.00000	TO	.00117
2	.00117	TO	.00590
3	.00590	TO	.01865
4	.01865	TO	.04553
5	.04553	TO	.09441
6	.09441	TO	.17490
7	.17490	TO	.29838
8	.29838	TO	.47794
9	.47794	TO	.72846

Figure 3-11. Grid Map for Dust Emissions from Off-Road Vehicle Activity, 1975.

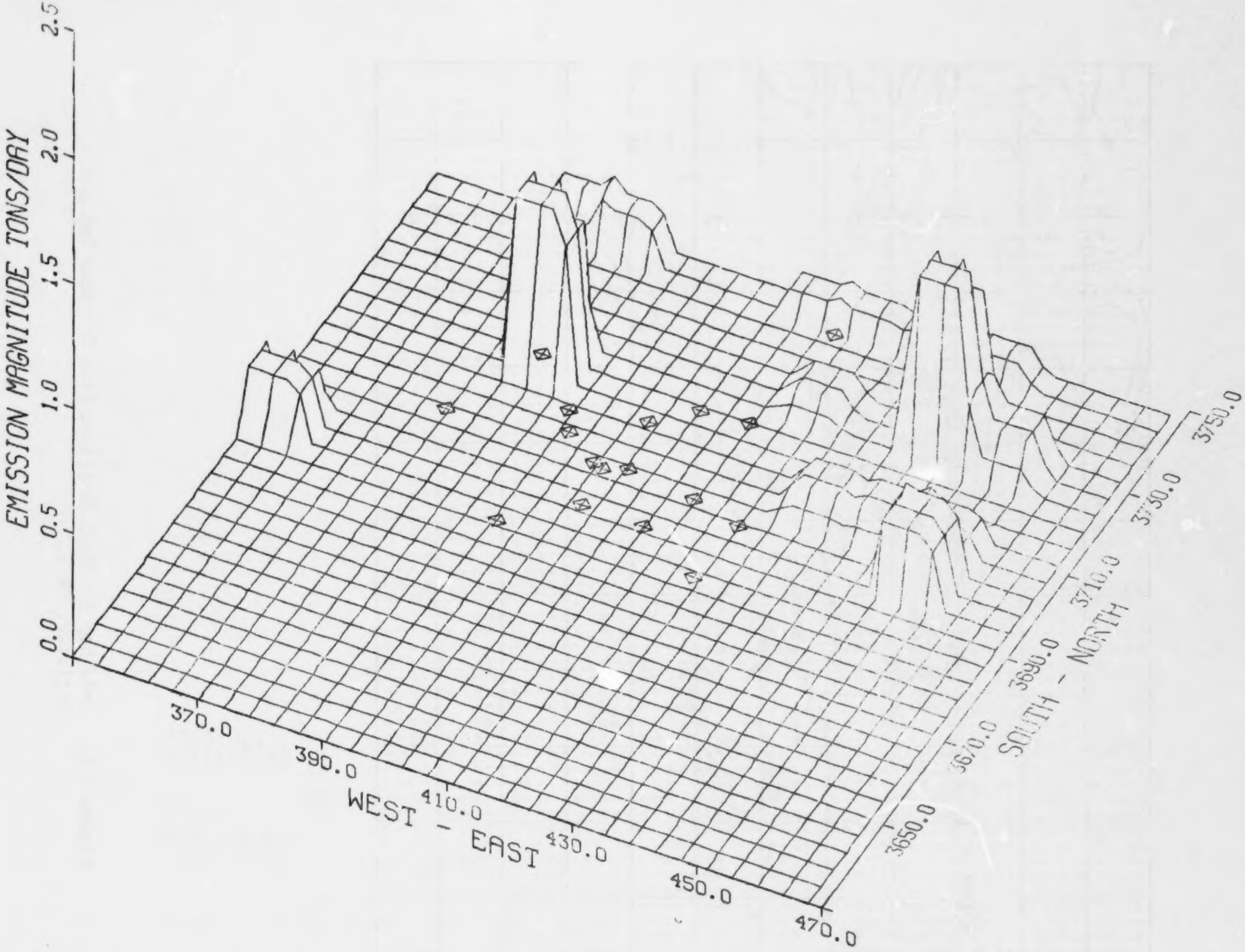


Figure 3-12. Daily Average Dust Emissions from Off-Road Motor Vehicle Activity, 1975.

3.6 FUGITIVE DUST FROM CONSTRUCTION ACTIVITIES

Construction activities inevitably result in the exposure and disturbance of soil. Fugitive dust is emitted both during the activities (i.e., excavation, vehicle traffic, human activity) and as a result of wind erosion over the exposed earth surfaces. The major types of construction occurring in Phoenix are flood control projects, roadway construction, and residential/commercial/industrial building.

Review of Previous Inventories

Fugitive dust arising from construction activities in 1970 was estimated previously by PEDCo. Emission rates were based on a field investigation from specific construction sites in Paradise Valley, Phoenix, and in Las Vegas, Nevada. The Paradise Valley site was an 80 acre residential development with a shopping center. The Las Vegas site was a 100 acre residential development. Particulate sampling stations were placed at various locations surrounding the construction sites. Measurements of particulate levels and wind were used to solve diffusion equations for source dust emission rates from the construction site. The tests indicated an average dust emission rate of 1.4 tons/acre/month from construction sites. This rate was applied to the number of acres of activity construction during 1970 to calculate an average daily dust emission level of 170 tons/day for Maricopa County.

Midwest Research Institute [1] has recently reviewed the PEDCo field experiments [2] including additional measurements from the test sites not available for the PEDCo analysis. The review resulted in derivation of dust emission rates consistent with the initial findings, but slightly lower. An average dust emission rate of 1.2 tons/acre/month for active construction was established.

Methodology for the Present Inventory

The previous studies sited above constitute the basic awareness available for deployment in the present study. Construction activities should be summarized in terms of acres of soil disturbed, and the single emission rate (1.2 tons/acre/month) is applied to all types of active construction to estimate total dust levels emitted.

Roadway construction activities for the study area in 1975 are summarized in Table 3-24. The county, the state, and each of the cities execute separate construction programs in the county. Based on average roadway clearing widths used in construction, the average area of exposed surface is calculated as shown in Table 3-25. the duration of active construction during which the road bed is exposed soil is generally about 6 months for a major road job of one mile length and 80 feet width, and about 2 months for each half a mile of local streets 33 feet wide [28]. Based on an average emission rate of 1.2 tons/acre/month, the dust emissions arising from road construction are shown in Table 3-25.

TABLE 3-24. SUMMARY OF ROAD CONSTRUCTION ACTIVITY IN PHOENIX AREA, 1975 [29].

RESPONSIBLE AGENCY	IMPROVEMENTS (MAJOR & LOCAL ROADS)	SUBDIVISION (PRIVATE CONSTRUCTION	FEDERAL AID SYSTEM	CITY OR COUNTY
	MILES OF ROADWAY			
County	20.0	56.0	15.8	128.7
Phoenix	26.4	58.7	3.6	1.4
Glendale	0	14.7	0	0
Paradise Valley	1.5	2.8	0	.6
Peoria	0	0	0	2.1
Mesa	0	32.7	0	0
Tempe	0	10.3	0	0
State Highway Dept.	0	0	36.8	0
	47.9[c]	175.2[b]	56.2[a]	132.8[b]

[a] Of those roads financed by federal aid, 18.9 miles are 4 lane highways 80' wide, and 37.3 miles are 2 lane highways 48 ft. wide.

[b] Average width of these roads is 33 feet.

[c] Average width of local and major roadways is 55 feet.

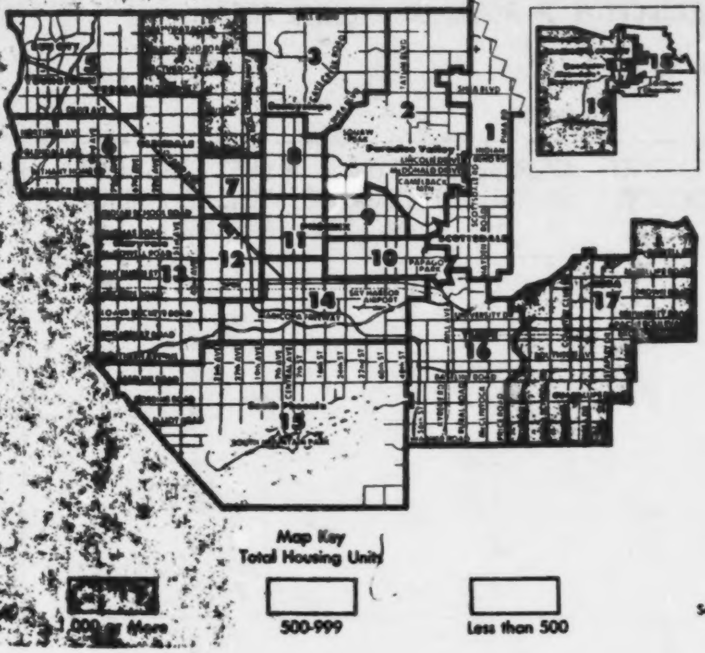
TABLE 3-25. DUST EMISSIONS ARISING DURING ACTIVE CONSTRUCTION OF ROADS IN PHOENIX AREA,

AGENCY	ACRES OF SOIL EXPOSED IN ROAD CONSTRUCTION	AVERAGE DURATION OF SOIL DISTURBANCE	DUST EMISSIONS TONS/DAY ANNUAL AVERAGE)
County	990	2.5 months	8.2
Phoenix	446	2.9	4.3
Glendale	59	2.0	.4
Paradise Valley	26	3.1	.3
Peoria	8	2.0	.1
Mesa	130	2.0	.9
Tempe	41	2.0	.3
State Highway Dept.	262	4.0	3.5
	1952		18.0

Because the magnitude of exposed soil area resulting from roadway construction is relatively small by comparison with other fugitive dust source areas, efforts to resolve this source spatially on the grid network were limited. Construction dust emissions for each of the cities was allocated evenly on the emissions grid network within the entire city boundaries, and road construction dust for the county and State Highway Department was apportioned evenly throughout the county portion of the study area.

The most significant source of construction dust arises during the building of residential/commercial/industrial structures. Residential housing comprises the major portion of the activity in this construction category. Figure 3-13 shows the distribution of housing units constructed during 1975. Most of the new housing was constructed around the perimeter of urbanized Phoenix, and overall construction activity was relatively light in 1975.

(Based on Building Permits Issued January through December, 1975)



District	Single	Townhouse	Multiple	Total Units
1	319	43	13	375
2	953	5	9	967
3	548	—	17	565
4	552	8	440	1,000
5	127	7	—	134
6	744	—	10	754
7	52	—	152	204
8	37	12	20	69
9	7	—	15	22
10	9	—	95	104
11	6	—	2	8
12	39	—	—	39
13	734	—	—	734
14	16	—	21	37
15	211	—	—	211
16	513	104	14	631
17	1,184	32	5	1,221
18	808	22	30	860
19	1,846	176	2	2,024
Total Metro Phoenix 1975	8,705	409	845	9,959
Total Metro Phoenix 1974	11,280	2,354	6,073	19,707
Per Cent Change 1974-1975	-22.8%	-82.6%	-86.1%	-49.5%

Source: Maricopa County Housing Study Committee, M. R. West Marketing Research, Inc.

Figure 3-13. New Housing Units in Maricopa County, 1975 [30].

Recent studies by the Maricopa County Planning Department [31] provide a basis for estimating the amount of disturbed soil associated with housing development. One study utilizes 1970 census data to develop the following occupancy rates for housing units.

Single Family Dwellings	3.45 persons
Multi-family Units	2.22
Mobile Homes	2.22
Weighted Average	3.14 persons/home

Another study [32] has established the relationship between land use and population in Maricopa County. Table 3-26 shows this relationship for various separate land use categories. These land use ratios have been employed by the Maricopa County Planning Department to forecast land use allocation consistent with population growth projections. The ratios were used in the present inventory as a basis for total amounts of land utilization in each of the land use sectors for 1975. First, residential housing

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TABLE 3-26. URBAN LAND USE RATIOS [32].

LAND USE CATEGORY	ACRES PER 100 PERSONS
Single-Family	5.20
Multi-Family	.85
Mobile Homes	.20
TOTAL RESIDENTIAL	6.25
TOTAL COMMERCIAL	.70
Light Industry	.55
Heavy Industry	.25
Railroads and Public Utilities	.40
TOTAL INDUSTRIAL	1.20
Streets and Alleys	3.45
Parks and Playgrounds	2.00
Public and Semi-Public	1.40
TOTAL PUBLIC AND SEMI-PUBLIC	6.84
TOTAL DEVELOPED LAND	15.00

land use was estimated by combining the land use ratios with average occupancy rates, 1975 housing construction data (Figure 3-13), and a housing unit inventory compiled by M. R. West Marketing Research, Inc. [30]. Average acreage figures per housing unit were established by housing unit type as shown in Table 3-27. These average rate figures were then employed to calculate disturbed soil areas associated with housing construction in each of the districts as shown in Table 3-28.

TABLE 3-27. LAND USE BY HOUSING UNIT TYPE IN MARICOPA COUNTY

	OCCUPIED UNITS [a]	PERSONS PER UNIT [b]	TOTAL PERSONS OCCUPING DWELLINGS	ACRES OF LAND USE PER PERSON [c]	ACRES PER DWELLING
Single Dwellings	299,300	3.46	1,035,000	.052	.242
Multiple Dwellings	120,000	2.22	267,000	.0085	.099
Mobile Homes	42,000	2.22	93,200	.0020	.066

[a] Reference [30]. [b] Reference [31]. [c] Reference [32].

TABLE 3-28. DUST EMISSIONS ARISING FROM CONSTRUCTION ACTIVITIES IN MARICOPA COUNTY, 1975.

DISTRICT	ACRES OF DISTURBED SOIL DURING HOUSING CONSTRUCTION			AVERAGE DUST EMISSIONS FROM HOUSING AND OTHER CONSTRUCTION[b]
	SINGLE DWELLINGS	MULTIPLE UNITS AND MOBILE HOMES[a]	TOTAL ALL HOUSING	TONS/DAY
1	77	7	84	3.1
2	232	2	234	8.6
3	133	2	135	4.9
4	134	55	189	6.9
5	31	1	32	1.2
6	180	1	181	6.6
7	13	19	32	1.2
8	9	4	13	.5
9	2	2	4	.1
10	2	11	13	.5
11	1	0	1	0
12	9	0	9	.3
13	178	0	178	6.5
14	4	3	7	.3
15	51	0	51	1.9
16	124	15	139	5.1
17	287	5	292	10.7
18	196	5	202	7.4
19	447	22	469	17.2
				83.0

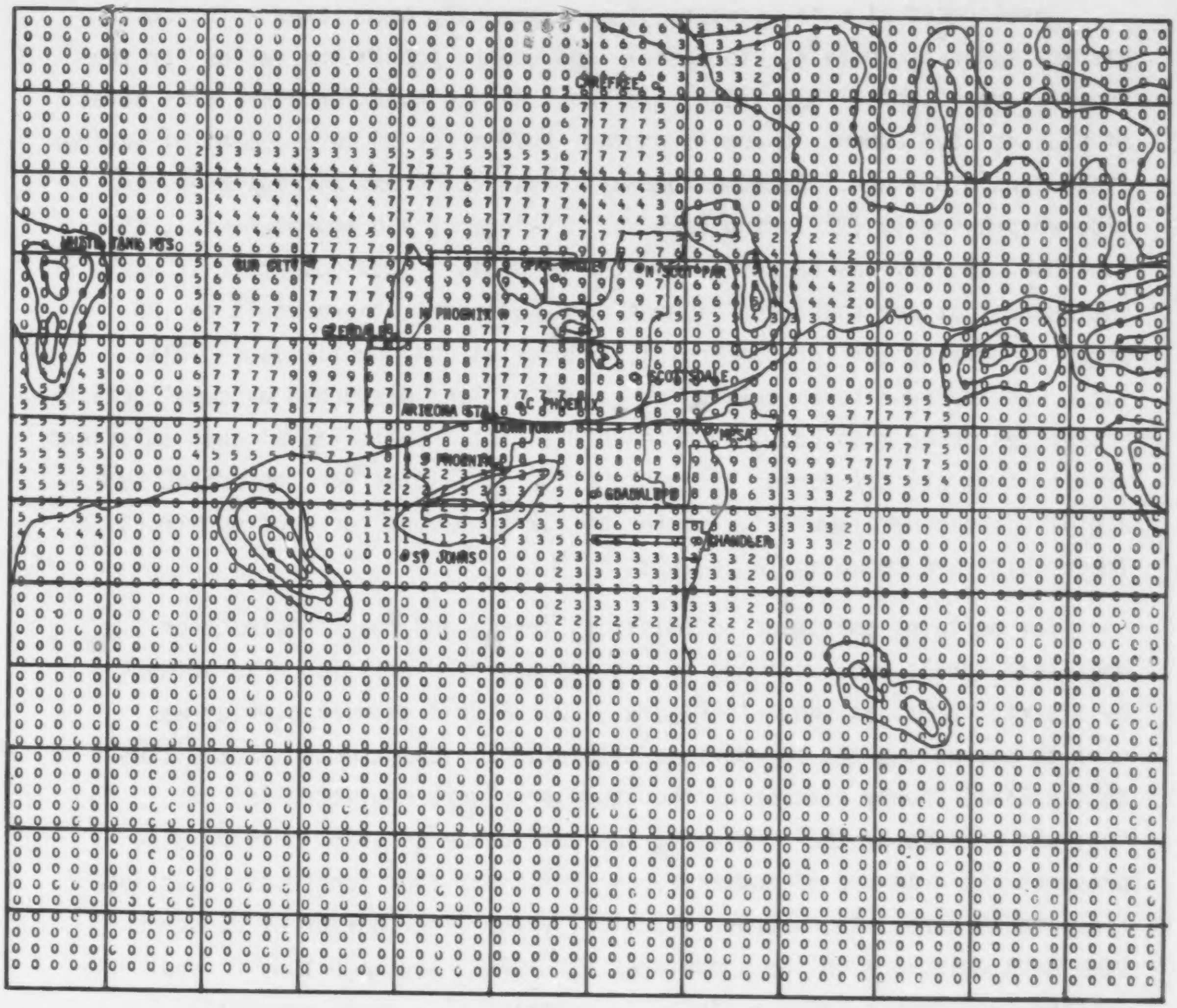
[a] The inventory of new mobile homes by district was not available. Therefore, mobile units were assumed to increase to the same degree as multiple and townhouse dwellings in each of the districts.

[b] "Other"construction land use average was estimated using historical land use ratios for the Phoenix area (Table 3-26). The ratio of "other" land use (excepting street use) to housing land use was computed to be .85. Dust emissions were calculated using the general emission rate 1.2 tons/month/acre of disturbed (developed) soil, applied for an average of 6 months active construction duration.

Development of other sectors of the community associated with housing was estimated by applying historical land use to population ratios for the Phoenix area (Table 3-26). These ratios indicate that for every 6.25 acres of housing development, there is another 8.75 acres of development of various other land use types. Because roadway construction has already been considered previously (including both new development and improvements), this land use category was deducted from the data base. Consequently, it was estimated that for each acre of housing development, there would be .85 acres of development for commercial, industrial, and public use. This ratio was employed to calculate the amount of land disturbed by construction activities other than housing for each district. Estimates of dust emissions arising from all categories of construction activities were generated by applying the general emission factor of 1.2 tons/month/acre of construction. The results are shown in Table 3-28.

The building construction emissions levels and road construction emissions levels were assigned to the computerized emission grid network by district areas as shown in Figure 3-13. A grid network overlay was used to accomplish the appropriate allocations. Construction activities in the Pinal County portion of the study area were neglected in the analysis because of their relative insignificance in 1975. Figure 3-14 presents the grid map of fugitive dust emissions from construction activities, and Figure 3-15 portrays graphically the distribution of construction dust emissions in the study area for 1975. The magnitude of dust loading from construction activity is substantial, and is generally distributed most heavily in the growth belt around the urban region of Phoenix. It should be noted that land use development during 1975 was greatly below the expectations reflected in the county planning forecasts, and represented the lowest dip in a recent decline of construction activity over the past several years. This pattern is expected to reverse sharply in 1976 and future years. Hence 1975 is probably non-representative with respect to dust emissions loadings occurring from construction.

The particle size distribution of construction dust emissions are expected to approximate that of the parent soil [33]. The predominant soil types in Maricopa County yield the following particle size distribution based on shallow core tests [11]:


CAREFREE
WHITE TANK MTS
SUN CITY
PAR VALLEY
N SCOT PAR
N PHOENIX
GLENDALE
SCOTTSDALE
ARIZONA STA
C PHOENIX
DOWNTOWN
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0.00000 TO .00000
1	.00000 TO .00059
2	.00059 TO .00296
3	.00296 TO .00942
4	.00942 TO .02299
5	.02299 TO .04766
6	.04766 TO .08830
7	.08830 TO .15064
8	.15064 TO .24130
9	.24130 TO .36776

Figure 3-14. Grid Map for Dust Emissions from Construction Activities, 1975.

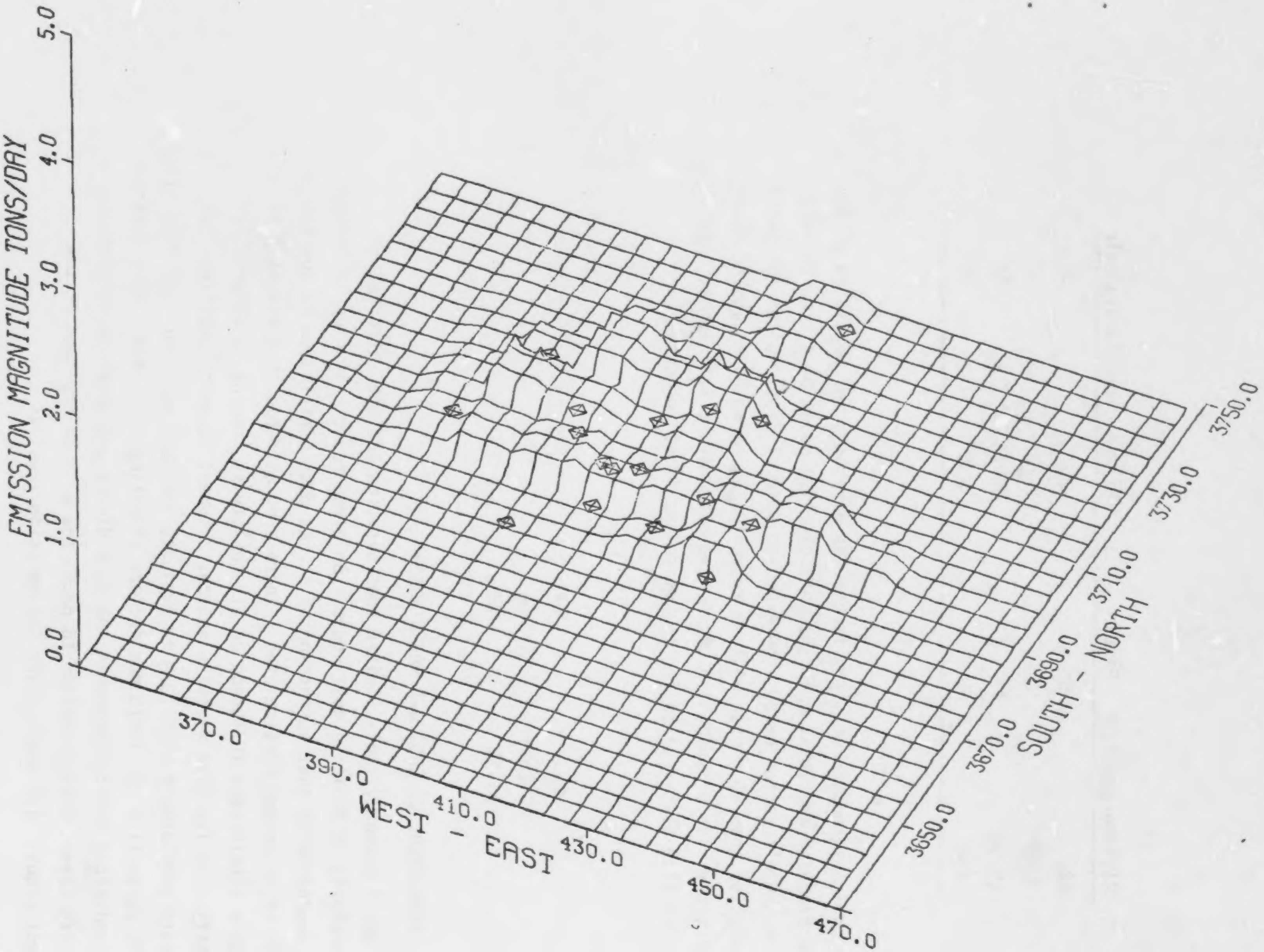


Figure 3-15. Average Daily Dust Emissions from Construction Activities, 1975.

Rillito-Gunsight - Pinal		Gilman-Estrella-Avondale	
<2μ	5%	<2μ	7%
2-20	10	2-20μ	20
20-50	17	20-74	35
>50	68	>74	38

Since the construction emission factor was developed for particles of 30 micron diameter and less, only the particle size below 30 micron is relevant in the discussion here. The expected aerosol distribution for particles smaller than 30 micron will be approximated based on an averaging of the particle size distribution of the two predominant soil types. The resulting size distribution for the emissions is as follows:

<2μ	21%
2-20	54
20-30	25

3.7 ENTRAINMENT OF DUST OFF PAVED ROADS

Until recently, only limited consideration had been directed to the analysis of fugitive dust sources on paved roads. Studies in Chicago [34] demonstrated that suspension of street dust contributed to substantial levels of suspended particulates. Increasing evidence that street dust exerts a significant influence on air quality is leading to efforts to quantify this fugitive emission source. Midwest Research Institute has recently completed a study[35] to evaluate the dust emission rate from streets and to parametize the influence factors affecting this rate. This general dust emissions model represents the most direct and complete attempt to quantify street dust emissions to date, and will be employed in the present study. The model gives the emission level as

$e = KLS$

where $k = 15 \times 10^{-5}$, an empirical proportionality factor

L = street surface dust load, g/curbed mile of road.

S = silt content of surface dust (usually about .10).

The dust loadings on a given roadway may vary significantly depending on several factors. Rain or street sweeping may reduce dust loadings to negligible levels for short periods. Accumulation of materials to an equilibium level after the washouts occurs rapidly, usually within 2 or 3 days. Equilibium is attained more rapidly after street cleaning, since often the cleaning process is only moderately effective. After rainfall, carry-over of mud collected under motor vehicles occurs at varying rates for several days until an equilibrium of street dust levels is attained. The equilibrium attainment rate has also been found to increase rapidly with higher vehicle speeds.

Street dust loadings for the Phoenix area are shown in Table 3-29. The limited number of measurements, and the lack of a definitive pattern of dust loads relative to street types does not warrant development of a separate emission rate for different street types in the present study. A weighted average of 780 lb/curb mile was selected as a representative dust loading for the entire population of curbed road types in Phoenix. Based on a study by American Public Works [36], the dust load level was increased by a factor of four for uncurbed streets.

Based on the appreciable proportion of unpaved road shoulders in metropolitan Phoenix, it is not unlikely that dust suspension off city streets would contribute greatly to the ambient particulate problem. There are 470 miles of city streets with unpaved shoulders in the city. Over half of these roads are major streets experiencing substantial traffic volumes. The ratio of uncurbed to curbed roads in the various unincorporated cities was assumed to be equivalent to that in the city of Phoenix. The county roadway system is comprised of approximately

TABLE 3-29. DUST LOADS ON STREET SURFACES OF PHOENIX [35].

Land Use	Loading Intensity (lb/curb mile) Site #1	 Site #2	 Mean
Residential			
low/old/single	770	1600	1185
low/old/multi	1900	1100	1500
med/new/single	180	380	280
med/old/multi	310	500	405
Industrial			
light	450	260	355
Medium	1300	1100	1200
Commercial			
central business area	210	200	205
Shopping center	640	180	410
Overall weighted mean	650	910	

95% uncurbed streets. There is an active city street sweeping program, including cleaning of major streets every 10 days, collectors every 2 weeks, and local roads once monthly. However, this program is only marginally effective with respect to controlling entrained dust levels, due to rapid deposition of surface dust which produces equilibrium levels of road materials within 2 or 3 days.

The silt content of the street surface dust load is controlled within a relatively narrow range by the mechanism of deposition-reentrainment equilibrium. Coarse dust aggregates are continuously being pulverized into finer particles which become suspended by traffic activity, and additional aggregates are continuously deposited on the roadway by vehicle carry over, dustfall from adjacent sources, motor vehicle exhaust, and tire and brake wear. Measurements have shown that the silt content of street surface dust is from 5 to 15% for a wide range of street and traffic conditions [37]. A value of 10% silt was assumed to be representative for Phoenix street dust.

Emission Estimates

The emission factors for resuspended dust off paved streets in Phoenix were calculated using the MRI model. They are:

Curbed roads	5.3 g/vehicle mile
Uncurbed roads	21.2 g/vehicle mile

These factors were applied to traffic volumes for each curbed and uncurbed link of the transportation link network in the study area. However, because the transportation tape does not identify the curbed or noncurbed status of the various road types, it was necessary to develop an overall weighted emission factor to be applied to the three major street categories (local, collector, major). The factor is weighted according to the proportion of miles of curbed to noncurbed streets as shown below. Local roads were omitted from consideration due to the insignificance of traffic volume on these streets relative to the total area VMT.

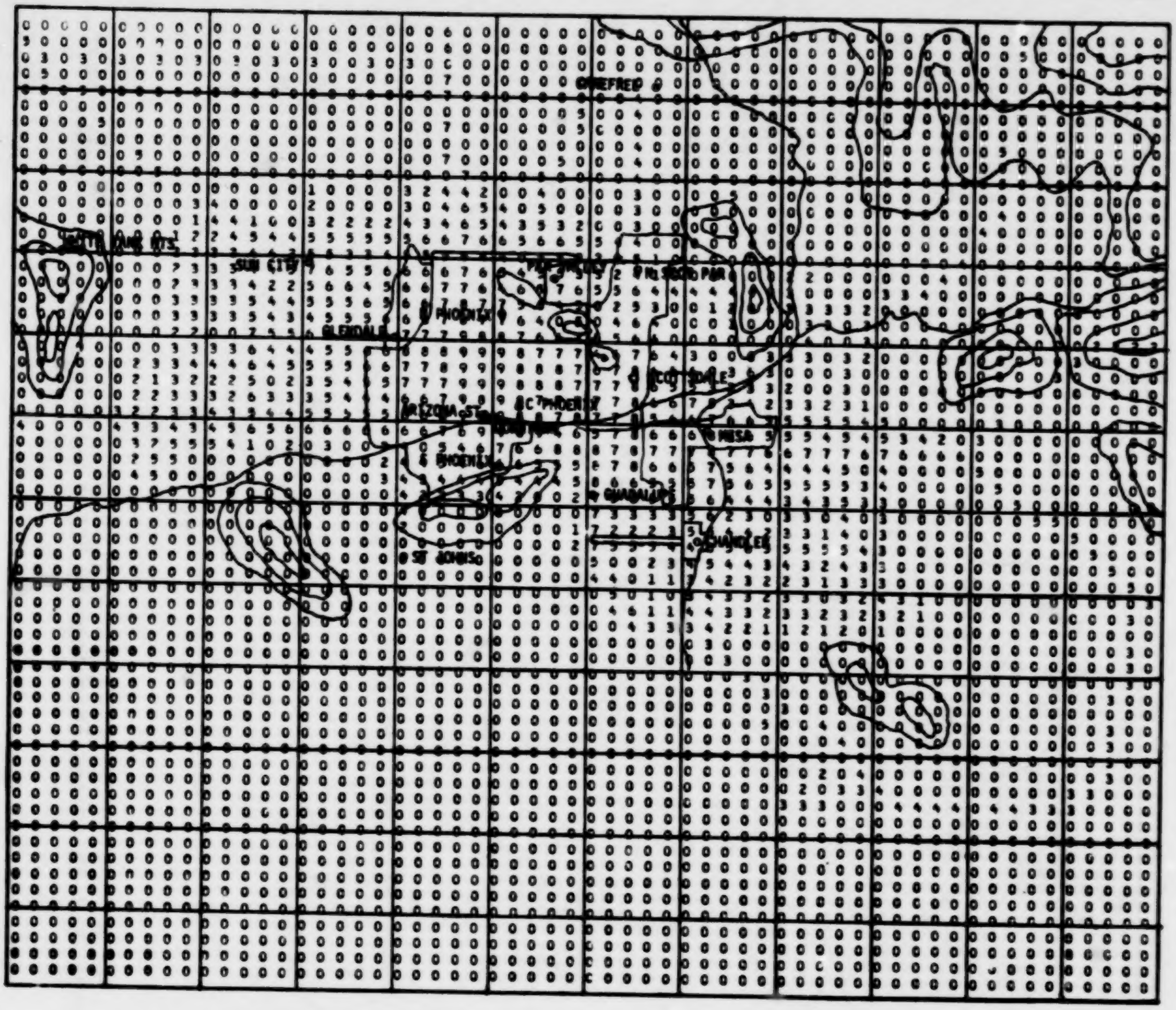
Street Type	Total Miles in City	Total Uncurbed Miles in City	Weighted Emission Factor for 1975
Major and Collector	900	329	11.1 g/vehicle mile

Emissions calculated for each link were assigned to grid squares of the study area grid network by means of the TRW emissions simulator software. The simulator operates on a computer tape of 1975 transportation link data (including designation for city and county roads) provided by the Arizona Department of Transportation. The software operations are essentially the same as those employed to estimate conventional motor vehicle source emissions (see Section 2.0).

Figure 3-16 illustrates the gridded emission inventory for entrained street dust. The magnitude of these dust emissions is significant, especially considering they are concentrated within the urbanized areas where other major fugitive sources, i.e., unpaved roads, agricultural) are absent. The distribution of the resuspended dust emissions is shown graphically in Figure 3-17.

The particle size distribution of the suspended street dust is given by MRI [35].

< 5μ	40%
5-30μ	60%


CAREFREE
WHITE TANK MTS
SUN CITY
PHOENIX
GLENDALE
SCOTTSDALE
ARIZONA ST
PHOENIX
MESA
PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY		
0	0.00000	TO	.00000
1	.00000	TO	.00389
2	.00389	TO	.01970
3	.01970	TO	.06227
4	.06227	TO	.15202
5	.15202	TO	.31523
6	.31523	TO	.58401
7	.58401	TO	.99630
8	.99630	TO	1.59987
9	1.99987	TO	2.43236

Figure 3-16. Grid Map for Dust Entrained by Motor Vehicles on Paved Streets, 1975.

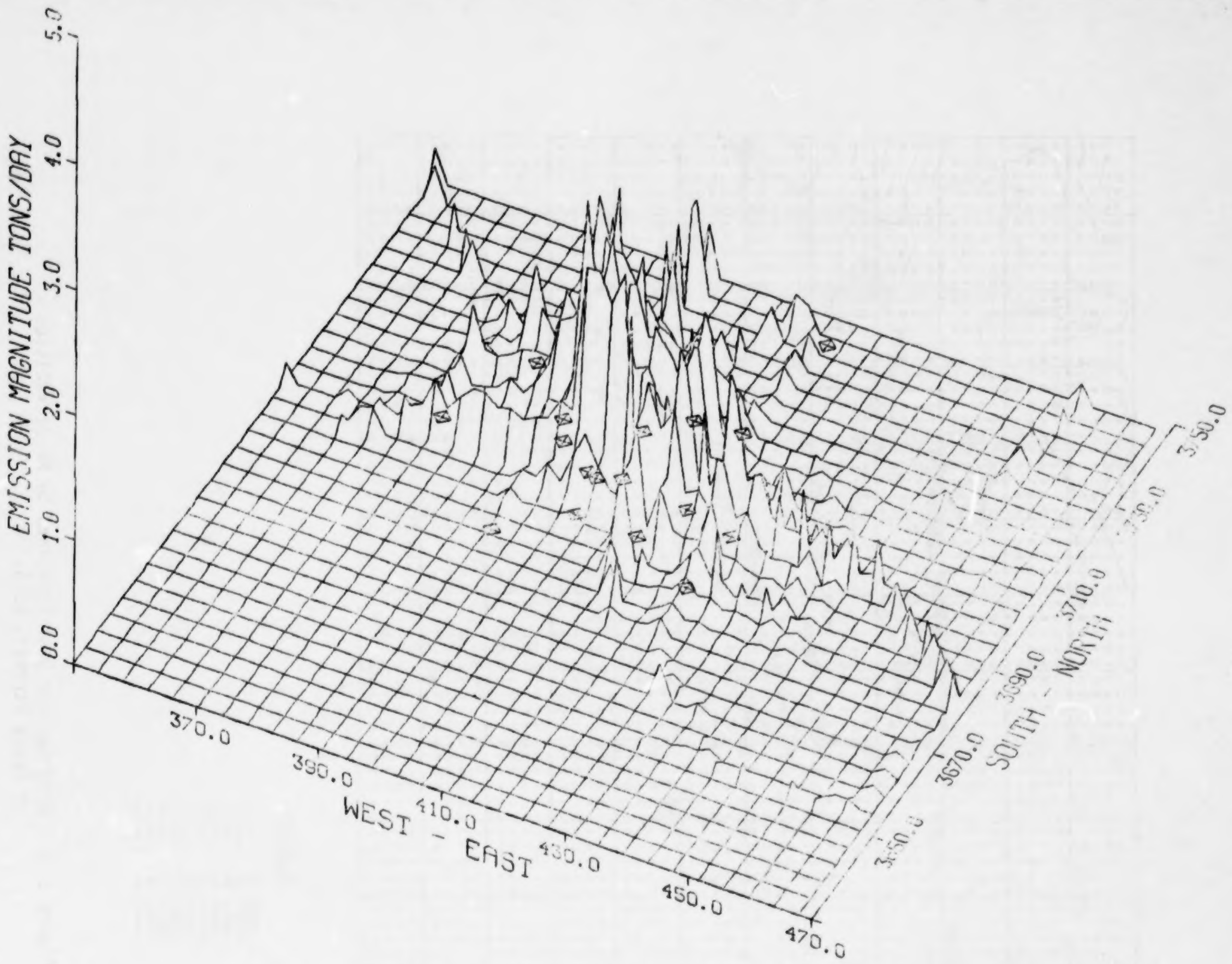


Figure 3-17. Average Daily Street Dust Emissions Entrained by Motor Vehicles on Paved Streets, 1975.

REFERENCES FOR SECTION 3.0

1. Midwest Research Institute, "Development of Emission Factors for Fugitive Dust Sources," prepared for the Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, June 1974.

2. PEDCo Environmental Specialists, Inc., "Investigation of Fugitive Dust, Volume I - Sources, Emissions and Control," prepared for the Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, June 1974.

3. "Air Pollution from Unpaved Roads," a research paper by the School of Engineering, University of New Mexico, January 12, 1971.

4. Hoover, J. M. "Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets," Final Report, by Engineering Research Institute, Iowa State University, ERI Project 856-S, submitted to the Iowa State Highway Commission, July 1973.

5. Anderson, C., "Air Pollution from Dusty Roads," as presented at the 17th Annual Highway Engineering Conference, 1 April 1971.

6. Roberts, J. W., et. al, "Cost and Benefits of Road Dust Control in Seattle's Industrial Valley," JAPCA, Vol. 25, No. 9, September 1975.

7. Arizona Department of Transportation, personal communication, March 1976.

8. Maricopa County Highway Department, personal communication, March 1976.

9. Maricopa Association of Governments, personal communication, March 1976.

10. Dr. Chatten Cowherd , Midwest Research Institute, personal communication, March 1976.

11. U. S. Department of Agriculture, Soil Conservation Service, "General Soil Map, Maricopa County, Arizona," Portland, Oregon, 1973.

12. U. S. Department of Agriculture, Soil Conservation Service, "Soil Survey - Eastern Maricopa and Northern Pinal Counties Area, Arizona," Washington, D. C., 1974.

13. U. S. Department of Agriculture, Soil Conservation Service, "Soil Survey Laboratory Data and Description for Some Soils of Arizona," Soil Survey Investigations Report No. 28, August 1971.

14. Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," U. S. Department of Health Education and Welfare, Public Health Service, National Air Pollution Control Administration, Cincinnati, Ohio, 1969.

15. Arizona Department of Transportation, Planning Survey Group, "Status of the Road Systems Mileage," June 1975.

16. Maricopa County Agricultural Agent, personal communication, April 1976.

17. Arizona Crop and Livestock Reporting Service,"Cropland Atlas of Arizona," Phoenix, Arizona, October 1974.

18. Arizona Crop and Livestock Reporting Service, "1974 Arizona Agricultural Statistics," Bulletin S-10, Phoenix, Arizona, March 1975.

19. U. S. Department of Agriculture, Soil Conservation Service, "General Soil Map, Pinal County, Arizona," Portland, Oregon, 1972.

20. U. S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors," Publication AP-42, Office of Air and Water Programs, Research Triangle Park, North Carolina, April 1973.

21. U. S. Forest Service, Phoenix, Arizona, personal communication, May, 1976.

22. Bureau of Land Management, U. S. Department of Interior, personal communication, May, 1976.

23. Phoenix City Parks and Recreation Department, personal communication, May, 1976.

24. Glendale City Parks and Recreation Department, personal communication, May, 1976.

25. American Motorcycle Association, Phoenix, Arizona, personal communication, May, 1976.

26. Tonto National Forest Service, Phoenix, Arizona, personal communication, May, 1976.

27. Phoenix 4-Wheel Club, personal communication, May, 1976.

28. City of Phoenix Department of Traffic Engineering, personal communication, May 1976.

29. State of Arizona Highway Department, personal communication, April 1976.

30. Phoenix Newspapers, Inc., "Inside Phoenix 1976," 1976.

31. Maricopa County Planning and Zoning Department, "Data for School Planning," April 1973.

32. Maricopa County Planning Department, "A Report Upon Future General Land Use for Maricopa County, Arizona," February 1975.

33. Gillette, D, and Blifford, I, National Center for Atmospheric Research, "The Influence of Wind Velocity on the Size Distribution of Aerosols Generated by the Wind Erosion of Soils," *Journal of Geophysical Research*, September 20, 1974.

34. Harrison, P., Draftz, R. and W.H. Murphy, "Identification and Impact of Chicago's Ambient Suspended Dust," Paper submitted to *Atmospheric Environment*, 1974.

35. Midwest Research Institute, "Quantification of Dust Entrainment from Paved Roadways," final report draft, prepared for Environmental Protection Agency, March 1976.

36. American Public Works Association, "Water Pollution Aspects of Urban Runoff," Chicago, 1969.

37. Chatten Cowherd, Midwest Research Institute, personal communication, May 1976.

4.0 BASEYEAR WINDBLOWN FUGITIVE EMISSIONS

In dry regions where large amounts of exposed earth are prevalent, entrainment of soil particles by force of wind may contribute significantly to total suspended particulate levels. The magnitude of windblown dust emissions varies dramatically with climate. Subsequently, the importance of windblown dust changes seasonally. Table 4-1 summarizes the dust emissions levels estimated to have occurred during the baseyear (1975). Of the five windblown dust sources investigated, only two are of major importance. Dust blowing from the undisturbed desert and from disturbed soils in and near the metropolitan area account for about one fourth of the total particulate emissions estimated for 1975. Emissions from the desert are substantial because of the vast amounts of this source that exist around the urban areas. Windblown dust from disturbed soil areas (vacant lots, parking lots, dirt residence yards) are substantial because of both the suspendable nature of the disaggregated surface soils, and the vast amounts of disturbed soil surfaces throughout the study area. Windblown dust emissions from agricultural fields are estimated to be relatively insignificant because of the consolidated structure of the irrigated soils and their subsequent resistance to suspension by wind.

The seasonal variation of windblown dust levels is shown clearly in Table 4-1. The combined effect of temperature, precipitation and wind speed produced progressively greater forces of soil wind erosion during each successive quarter of 1975. However, this pattern is atypical, as the second and third quarters usually produce the conditions causing greatest wind erosion. Also (as will be shown in Section 4.2 and later in Section 5.0), climatic conditions during 1975 were conducive to levels of wind erosion approximately three times as great as that corresponding to "typical" conditions.

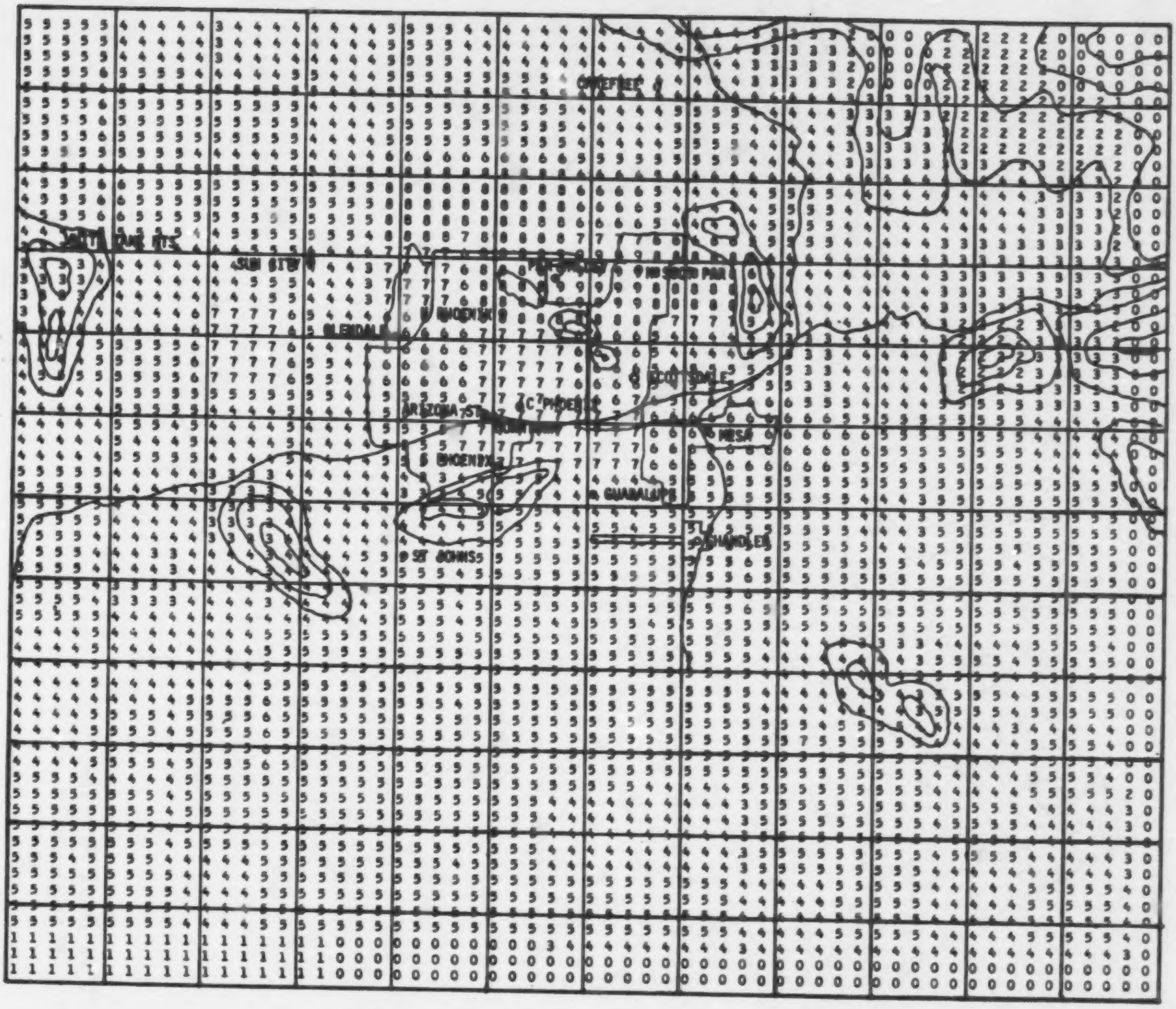
The windblown dust emissions are inventoried spatially according to the grid network described previously in Section 2.0. Figure 4-1 presents the gridded emission inventory for total windblown fugitive dust emissions for the baseyear. Figure 4-2 is a graphical portrayal of the emissions grid. It can be seen that dust emissions caused by

TABLE 4-1. WINDBLOWN FUGITIVE DUST IN PHOENIX STUDY AREA, TONS/DAY.

SOURCE CATEGORY	1st QUARTER	2nd QUARTER	3rd QUARTER	4th QUARTER	ANNUAL
Agricultural fields	4.1	4.0	3.8	4.0	4.0
Unpaved Roads	1.4	2.1	2.7	3.8	2.5
Undisturbed Desert	160	244	321	450	294
Tailings Piles	1.4	1.4	1.4	1.4	1.4
Disturbed Soil	161	248	323	456	297
TOTAL	328	500	652	915	599

wind erosion are most prevalent in the northern suburbs of the metropolitan area, where there are vast areas of undisturbed desert as well as disturbed vacant lands.

The physical mechanisms causing entrainment of soils by wind are not fully understood, and empirical data describing the atmospheric-surface exchange of soil particles is relatively limited. Accordingly, methodology now available to estimate windblown dust levels is somewhat crude. The methodology currently in practice involves simplified versions of the wind erosion equation, adapted to include a suspension factor for the portion of eroded soil which is entrained. Section 4.1 describes the general methodology of the wind erosion model employed in the estimates of this study. Section 4.2 through 4.6 document the specific assumptions and procedures utilized to generate emissions estimates for the various sources identified in the study.


CAREFREE
TANK MTS
SUN CITY
GLENDALE
PHOENIX
SCOTTSDALE
ARIZONA ST
MESA
PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0.0 TO 0.0
1	0.0 TO 0.003
2	0.003 TO 0.01
3	0.01 TO 0.04
4	0.04 TO 0.11
5	0.11 TO 0.23
6	0.23 TO 0.42
7	0.42 TO 0.72
8	0.72 TO 1.10
9	1.10 TO 1.70

Figure 4-1. Fugitive Dust Emissions Arising from Wind Erosion, Average Daily Emissions, 1975.

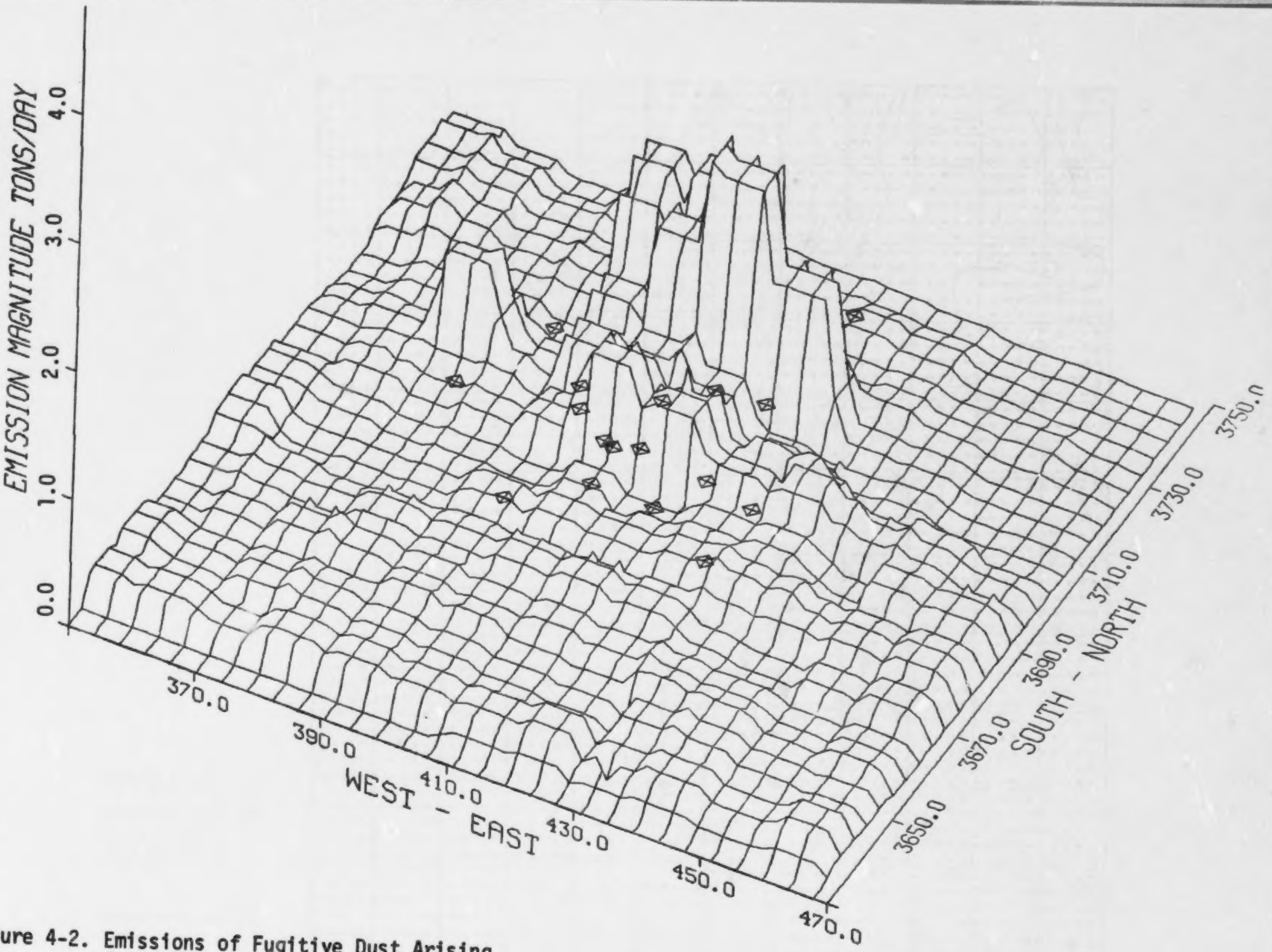


Figure 4-2. Emissions of Fugitive Dust Arising from Wind Erosion, Average Daily Emissions, 1975.

4.1 GENERAL METHODOLOGY FOR PRESENT INVENTORY

Only limited attention has been directed to the understanding of dust suspension resulting from wind erosion of soils. In a recent literature survey of available methods of estimating soil entrainment [1], Midwest Research Institute concluded a most appropriate method of estimating wind blown soil emissions would involve use of wind erosion relationships developed by the U.S. Department of Agriculture. It was evident that the horizontal movement of soils is caused by the same factors which affect suspension of the soils. However, the exact mechanisms causing entrainment of the soils is only recently being fully understood. The quantification of these mechanisms (direct aerodynamic entrainment and surface sand blasting) for application in air pollution studies will not be available in the short term. It appears the best approach at present is to assign a suspension rate to the horizontal soil movement as determined by the established wind erosion equations. This approach has been used recently in studies concerning control of fugitive dust emissions.

The most relevant treatment of the wind erosion equation for the present study is provided by the recent MRI review of fugitive dust sources [1]. This is a simplified version of the basic wind erosion equation, given by

$$E_s = AIKCL'V'$$

where:

E_s = suspended particulate fraction of soil wind erosion losses, tons/acre/year

A = portion of total wind erosion losses that would be measured as suspended particulate

I = soil erodibility, tons/acre/year

K = surface roughness factor, dimensionless

C = climatic factor, dimensionless

L' = unsheltered field width factor, dimensionless

V' = vegetative cover factor, dimensionless.

The variable of greatest uncertainty in the adopted wind erosion relationship is the suspension factor A. Only limited data are available to characterize the mechansim of soil particle suspension generated by the wind erosion of soils. Qualitatively, it is known that the suspension rate depends on the soil structure and the wind speed. Two aspects of soil structure are important: 1) the distribution of particle sizes, and 2) the aggregate structure of the soil. Gillette [4] showed that increased agitation of the soil disconsolidated the silt-sized soil aggregates, and caused increased concentrations of suspended soil dust for a given wind velocity. The undisturbed desert soil surfaces are generally composed of silt aggregate and a thin crust of gravel and sand. This crust is easily disaggregated. Human activities in the open desert disturb the soil consolidation and produce soil surface susceptible to suspension by wind. The high erodibility of these disturbed soils results in a higher fraction of suspended particles from the mass of eroding soil. Agitation of soil can also occur from the mechanism of wind erosion itself. Gillette observed that the dominant mechanism of fine soil wind erosion and suspension is sandblasting of the soil surface once soil movement has begun. Soil movement begins to occur at a threshold wind speed determined by the degree of consolidation of the soil surface. At higher wind speeds, sandblasting of the surface releases soil fines and a greater proportion of the moving soil mass becomes suspended.

The traditional concern in wind erosion studies involves quantification of soil losses, mostly for agricultural purposes. The objectives of these studies do not concern the issue of soil suspension. Consequently, very little empirical data has been obtained to establish the relationship of the suspension ratio of eroded soil with wind speed and soil type. In some of the earlier experiments, Chepil [3] estimated that 3-to-40% of soil movement is in suspension. In a recent study, Gillette [4] measured the vertical flux of particles ($<20\mu$) associated with a sand flux in horizontal movement by wind erosion and found the fraction of suspended particles to vary from 2×10^{-5} to .019 depending on soil type and wind velocity. For higher wind velocities, the Gillette experiments give a low value for vertical particulate fluxes as only the 2 to 10μ diameter range were measured. Since parent soils generally contain the greatest portion of particles greater than 50μ in size, the suspension fraction may be appreciably greater than that measured, particularly when wind speeds are sufficient to support suspension of larger particles. Gillette has shown airborne particle distributions are relatively independent of wind speed for particles far in excess of 20μ diameter [7]. Figure 4-3 shows this relationship for soil particles at several wind speeds for particle sizes up to 30μ radius. Figure 4-4 illustrates the suspension/settling characteristics for particles of different sizes as a function of wind speed.

Shinn has formulated a model to estimate vertical dust flux [8]. The model depends on parameters which should be determined for a given region, and Shinn suggests a general index for dry nonvegetated sites similar to that studied in the investigation. The model relates soil emissions to frictional wind velocity as follows:

$$F = F_0\left(\frac{U_*}{U_0}\right)^{(\gamma + 1)}$$

The coefficients F_0 and γ are determined by the soil surface properties, and Shinn suggests the values are related to the soil errodibility index accordings to the characterization of Figure 4-5. γ is shown to increase to values of 7 or 8 for soils of high errodibility. The GMX data shown

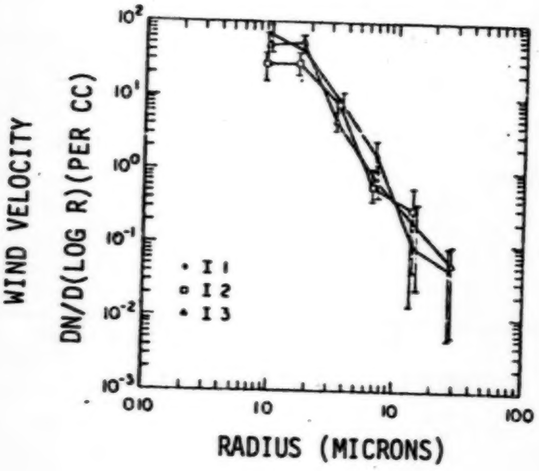


Figure 4-3. Size Distributions of Aerosols Obtained During Soil-Blowing Wind Tunnel Experiments. Friction Velocities were 11, 113,12,97,13,74 μm/sec [7].

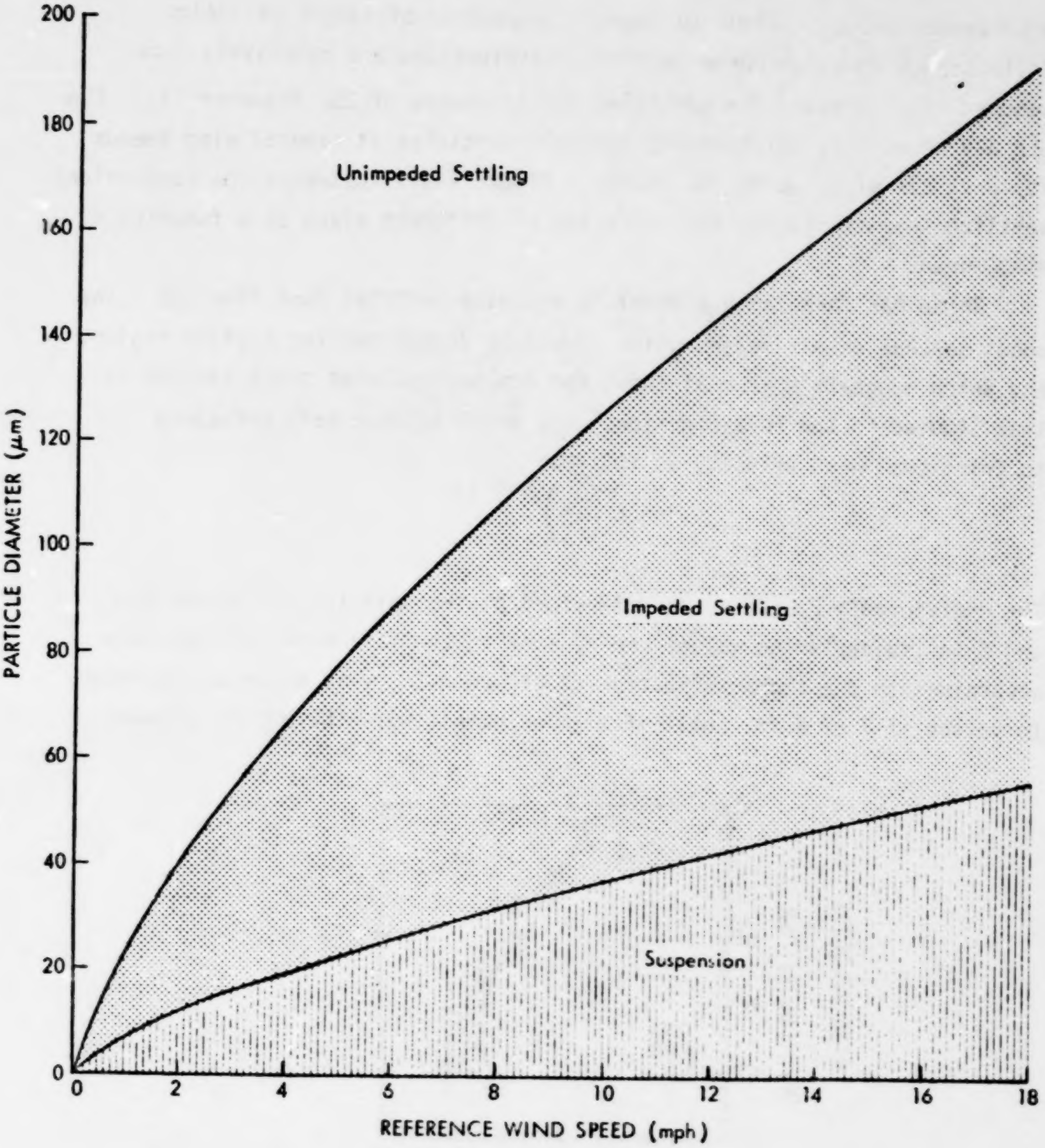


Figure 4-4. Particle Settling/Suspension Regimes [1].

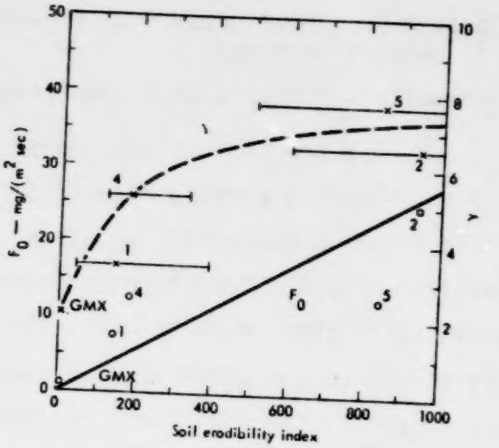


Figure 4-5. The effect of Soil Errodibility Index on Reference Dust Flux F_o and the Power γ of the Shinn-Gillette Dust Model [8].

in Figure 4-5 involved tests on the Nevada desert. The surface was undisturbed desert pavement exhibiting many pebbles and a crust surface with around 10% desert shrub cover 60 in. high. The parametrized form of the model at the Nevada site is:

$$F = .73\ V_*^{3.1}\ \text{mg/m}^2\text{sec} \qquad \text{ton/acre/day}$$

where V_* = frictional wind velocity

Midwest Research Institute [9] has recently developed an emission factor for wind-suspended dust based on the wind erosion equation:

$$E = .0089\ \frac{esV}{(PE/50)^2}\ f$$

where
E = emissions of suspended dust in tons/acre/year
e = Soil erodibility in tons/acre/year
s = percent silt content of surface soil

f = fraction of time wind exceeds the threshold value for wind erosion (12 mph)

V = mitigative fractional reduction in wind erosion due to vegetative cover

PE = Thornthwaite's Precipitation-Evaporation Index.

This version assumes a constant fraction of the eroded soil is suspended, and bases the value of the constant on data from Gillette findings. A significant modification to the wind erosion equation concerns MRI treatment of the wind speed term. In the traditional use of the wind erosion equation, wind speed was considered in calculating the climatic factor, entering as U^3 in this term. In the above version, dust emissions are not related to wind speed, except as the fraction f represents the extent of time to which the threshold wind speed is exceeded.

PEDCO [2] compared estimates derived from wind erosion equation applications to field test results and found fair agreement when assuming a constant 10% suspension ratio for wind-blown soils on unpaved dirt roads. It should be noted that PEDCO assumed a rather high errodibility index (77 ton/acre/year) for the soil surfaces of dirt roads. This index was based on silt measurements of the native soils of the area and is not representative of the true errodibility of unpaved road surfaces in the study area (see Section 3.1). For agricultural cropland soil erosion emissions, PEDCO assumed a 2.5% suspension rate. Dust emissions calculated from the wind erosion equation were apparently in agreement with those actually measured in the field.

Table 4-2 provides a comparison of suspension rates derived from results of the investigations discussed above. The suspension factors have been derived by calculating the ratio of measured suspended dust and calculated horizontal soil movement (based on the wind erosion equation). For the Gillette experiments, an additional "actual" factor can be calculated, since measurements of both horizontal and vertical flux were performed during the study. Excepting the estimates from the Shinn Model, the range of calculated suspension factors (ratio of measured emissions to calculated wind erosion losses) varies from .6% to 6.7%. The anomolous high fluxes and suspension factors calculated from the Shinn Model apparently

TABLE 4-2. FRACTION OF SOIL LOSSES SUSPENDED, AS DERIVED FROM AVAILABLE TEST RESULTS

	GILLETTE Wind Speed = 14 mph	Wind Speed = 14 mph	SHINN GILLETTE [d] $F = F_o\left(\frac{V_*}{V_o}\right)^{\gamma+1}$ Wind Speed = 14 mph	Wind Speed = 6 mph	MRI $E = .0089\frac{esv(50^2)f}{PE^2}$ Average wind speed =7.8 mph (46% of time exceeding 6 mph)[c]	PEDCO Wind Speed = 6 mph	
Erosion - Horizontal Flux as measured(tons/acre/year)	1300 (Measured)	151,000 (Measured)					
Soil Erosion, as calculated from soil erosion equation (tons/acre/yr.)	3460[b]	2540	16.1[a]	1.27[a]	2.77[a,d]	90	
Vertical Flux of soil particles (tons/acre/yr)	20 (measured)	22 (Measured)	24.7 (Calculated)	1.76 (Calculated)	.051 (Calculated)	6.0 (Measured/Calculated)	
Suspension Fraction (vertical flux/soil erosion)	.015(actual) .006	.0001(Actual) .009	1.54	1.39	.018	.067	.025
Soil Characterization	Previously Cultivated cropland, follow for several years and partially covered with grass.	Previously cultivated cropland follow for several years	Undisturbed desert pavement	Undisturbed desert pavement	Undisturbed desert pavement	Dirt roads	Agricultural fields

[a] based on soil characteristics assumed to be representative of Arizona or Nevada desert pavement.

[b] based on soil data reported by Gillette [4].

[c] these conditions correspond to meteorology observed in Phoenix during 1975.

[d] soil erosion loss is calculated here for the single average wind speed of 7.8 mph.

reflect the interference of local fugitive sources reported to occur [24] during the field flux measurements, and do not appear to be representative of potential dust levels blowing off undisturbed desert pavement.

There is evidence (Gillette, Shinn) that the suspension factor varies inversely with the soil errodibility index, directly with the soil errodibility index, and directly with wind speed [4,8]. This would suggest that suspended soil losses should be estimated utilizing probability functions for wind speed, and unique parameters associated with the soil types. However, only inexact and tentative parametrizations (such as the Shinn-Gillette model) are available at this time. For general applications, it does not appear that the present state-of-art can be used to support emission parametrizations more precisely than previous attempts. That is, emissions should still be calculated by assuming a certain constant fraction of the soil erosion losses (as calculated by the wind erosion equation) are suspended. This approach, should however, reflect representative and current data. Accordingly, the following suspension factors were proposed for use in the present study:

Soil Surface Category	Dust Suspension Factor
Croplands	.025
Unpaved dirt roads	.009 to .067
Undisturbed desert pavement	.018
Disturbed native soil (parking lots, residence yards, excavation clearnings)	.009 to .067

The selected range of the suspension factor for unpaved dirt roads reflects the Texas test results (Gillette), as well as, measurements conducted for dirt roads in the Southwest desert areas by PEDCO. Because the Gillette experiments were not concerned with measuring flux for particles > 20μ diameter, the suspension rate .009 is probably an understatement of the expected suspended soil losses. Figure 4-4 shows that for wind speeds of 10 mph (within standard variance of average wind in Phoenix), particles up to 40μ diameter remain suspended indefinitely. Therefore, it would not be unexpected that total soil emissions be substantially greater than those measured for the range $d < 20\mu$. On the other hand, evidence from numerous studies [1,9] indicate the suspension fraction of .067 derived from PEDCO may be high. Adjustment for each extreme of the range for the unpaved road suspension factor suggests that a median value between .009 and .067 be used for the present inventory. This value will be applied to other soil surfaces which experience disturbance, such as unpaved parking lots, private residence yards, and cleared vacant lots.

The suspension rate corresponding to estimates of dust emissions using the MRI model appears to be most consistent with an expected value which would apply for wind blown dust off undisturbed desert. However, for greater wind velocities, the calculated suspension rate of the soil erosion losses (MRI derived vertical flux/horizontal soil movement calculated by wind erosion equation) decreases, since the MRI model does not depend on a power term of wind velocity as does the wind erosion equation. Since it is not clear that the confidence associated with estimates derived from the model is greater than that obtained with the coupling of a suspension factor and the wind erosion equation, the latter emissions estimating procedure was employed, and a constant suspension factor of .018 was adopted. Section 4.4 describes this selection in further detail.

The PEDCO suspension estimate appears to be the most representative value which may be assigned for calculation of suspended agricultural soils.

There is presently limited data available to confirm the suspension factors selected for this study. Moreover, it is unlikely that the concept of suspension factor will be appropriate as further investigations are performed. What is needed are a series of parameterized relationships directly describing the vertical flux of soil particles. In the absence of such information, the crude assumptions identified above were utilized as the basis for estimating the suspendable portion of wind erosion losses.

In contrast to the difficulty in evaluating reasonable values for the factor A, the procedure for employing the remaining portion of the MRI version of the wind erosion equation is well-established. The remaining parameters comprise the major elements of the basic equation which is a result of 30 years of research to determine the primary factors that influence erosion of soil by wind. In the following sections of this chapter, area-specific values for the various factors are developed and utilized to calculate wind erosion losses and suspended dust emissions. Seasonal emissions are estimated for each square of a spatial grid network designed to enclose a 120 km by 120 km area around the urban center of Phoenix. The gridded emissions inventory is computerized for convenience of emission calculations, presentation, and for expedient evaluation of emission control alternatives later in the project.

4.2 WINDBLOWN EMISSIONS OFF UNPAVED ROADS

Two mechanisms are responsible for dust generation from unpaved roads. First, soil particles are injected into the atmosphere by forces of wheels and air currents from motor vehicle traffic. Second, soil particles are injected into the atmosphere when movement of the soil by wind action occurs. The former pick-up mechanism has been the subject of considerable interest in most fugitive dust studies, while wind-blown dust from unpaved roads has seldom been addressed. Depending on soil type, meteorology, and vehicle traffic, fugitive dust emissions from wind erosion of unpaved roads may be a significant cause of suspended particulate levels.

Review of Previous Inventories

Of those studies reviewed by MRI, only the PEDCO investigation has included an estimate of dust emissions arising from wind erosion on unpaved roads. In that study, wind-blown dust was assessed to contribute about 42% of all dust suspended from unpaved roads. Emission values were estimated by utilizing the theory of the wind erosion equation and region-specific data for meteorology, soil, and the unpaved roads. The wind erosion equation calculations were validated by relating 24-hour and 48-hour hi-vol field test values to a continuous line source air diffusion equation with the unknown term as the emission rate. The suspended wind erosion losses from unpaved roads in Phoenix was estimated to be 3.0 tons/acre/year. Based on average traffic counts and vehicle miles traveled, PEDCO expressed the wind blown emission rate as 1.54 lb/vehicle mile.

Methodology for the Present Inventory

Wind-blown dust emissions from the unpaved road network were estimated for each of the designated county maintenance or township areas (described previously in Section 3.0) by assigning area specific values to the variables of the MRI form of the wind erosion equation. Two basic road types are considered: gravel and dirt. The configuration of each type is assumed to be equivalent, but the soil characteristics of each type were distinguisable by maintenance areas or townships. The following discussion relates the procedures employed to assemble representative values of the erosion equation parameters, as well as, total emission estimates.

Soil errodibility of the unpaved road surfaces was determined by relating silt content of the road surface to errodibility as shown in Figure 4-6. The value presented represents the potential soil loss in tons/acre/year from a wide, unsheltered, isolated field with a bare, smooth, non-crusted surface. The silt content of the roads throughout the study area was determined by actual measurements as described in Section 3.1. Table 4-3 summarizes the silt content and errodibility of roads located in the predominant soil associations in the study area. As indicated, the silt content of soils on unpaved roads reaches an equilibrium value substantially less than that of the native soil. Consequently, roadway surfaces are generally relatively resistant to wind erosion. The data of Table 4-3 and a general soil map [6] were employed to assign a representative errodibility value to the unpaved roads in each of the roadway maintenance or township areas. The unit of spatial resolution (maintenance and township areas) was selected based on the format in which roadway data was available (see Section 3.1).

The surface roughness factor K for dirt roads was assumed to be 1.0. It is not expected that the limited number of ridges worn in dirt roads would affect the value of K significantly.

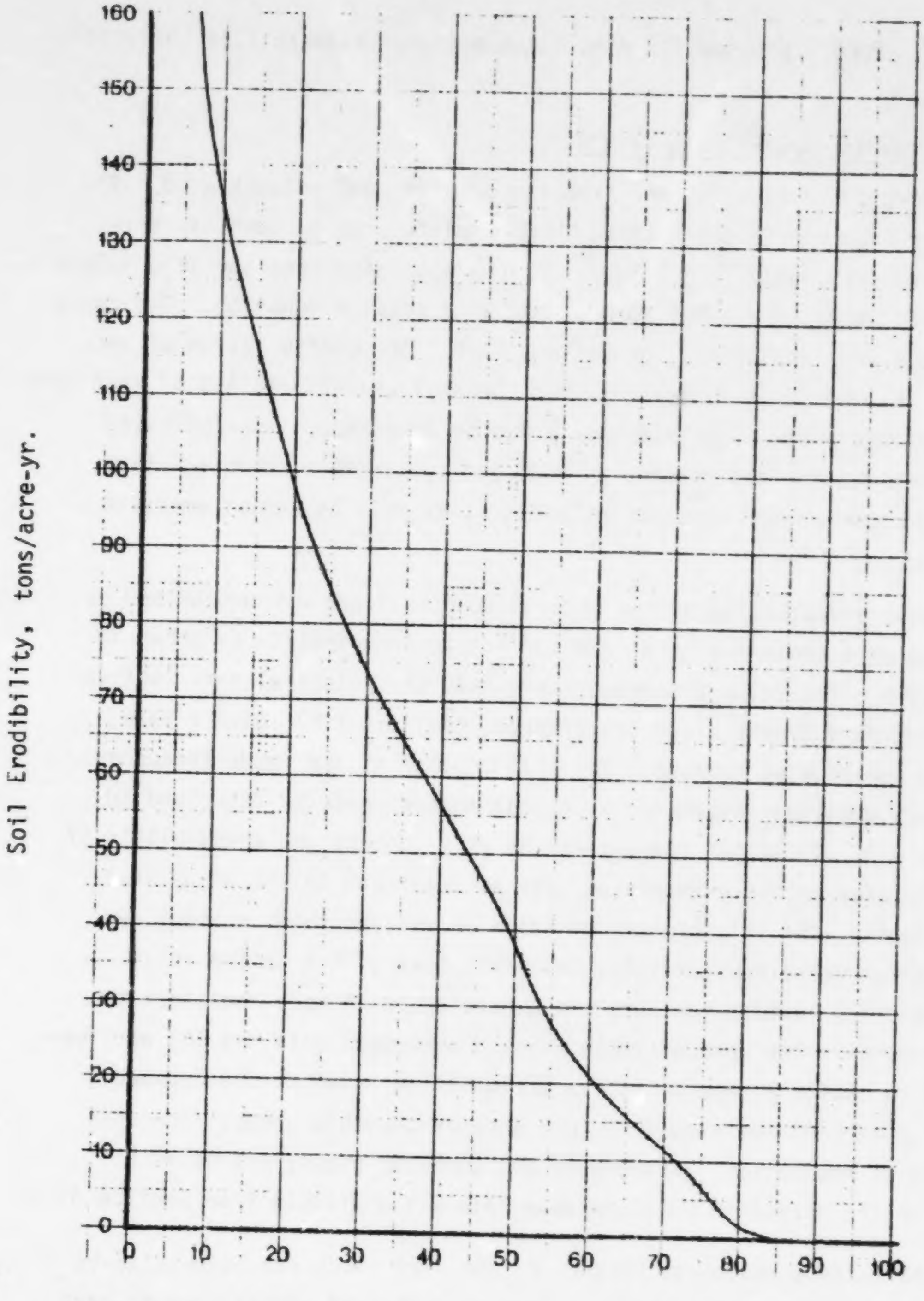


Figure 4-6. Soil Erodibility as a Function of Particle Size [1].

TABLE 4-3. ERRODIBILITY OF UNPAVED ROAD SURFACES IN PHOENIX AREA.

Soil Type	Silt Content[a] of Road Surface,%[b]	Silt Content[a] of Native Soil,%	Errodiability of Road Surface[c] Tons/Acre/Yr.
Gilman-Estrella-Avondale	27.2	55-80	8
Mohal-Contine	14.2	55-80	0
Ebon-Pinaimt-Tremant	23.3	15-45	5
Rock Outcrop	12.4	10-30	0
Gravel Road	12.0	-	0

a. Silt content is defined as the percentage (by weight) of soil particles less than 75μ in diameter.

b. Determined from field tests conducted by TRW in May 1976.

c. Determined by relating measured silt content to errodibility according to Figure 4-6. The measured silt level (particles smaller than 75μ) was assumed to approximate closely the parameter used in Figure 4-6 to determine errodibility (% of particles smaller than 84μ).

The climatic factor C was calculated to reflect seasonal variations in temperature, precipitation, and average wind speeds for the Phoenix area. While it is recognized that the wind erosion equation has been derived for annual averages, it is also evident that seasonal variations in meteorology will affect wind erosion in the short-term. This effect was accounted for by calculating "seasonal climatic factors" and inserting these values in the wind erosion equation to forecast seasonal wind erosion levels. Table 4-4 summarizes the tabulation of seasonal factors for 1975 and for long-term historical meteorology for the area. The differences between factors in 1975 and those based on annual average climate are due to the transient moisture content of the soil and the changing magnitude of wind speed. Soil moisture content is determined by the cumulative balance between precipitation and evaporation. The Thornthwaite Precipitation Evaporation Index (PE Index) was formulated to express this net moisture exchange between soil and atmosphere. The index is a measure of cumulative moisture balance over the past 12 month period. Table 4-4 shows that moisture content in the Phoenix area was highly variable during 1975 as low rainfall and high temperature caused the

PE Index to diminish from 8.8 in the first quarter to 5.3 in the last quarter. Average wind speeds were also greater than the historical averages for each of the seasons in 1975. These factors contributed to an unusual seasonal pattern for the climatic factor C, as well as, values of C which were appreciably higher than usual historical levels.

Table 4-4. Seasonal Climatic Factor, C, in Phoenix Area for 1975 and Historical Long-Term Averages

Period	Quarterly PE Average[a]	Average Wind Speed, w (mph)	$C = .345 \frac{w^3}{(PE)^2}$
1975			
1st qtr.	8.8	7.2	1.7
2nd qtr.	8.8	8.4	2.6
3rd qtr.	7.7	8.3	3.4
4th qtr.	5.3	7.3	4.8
Historical Averages			
1st qtr.	9.4	5.6	0.7
2nd qtr.	9.4	6.7	1.2
3rd qtr.	9.4	6.5	1.1
4th qtr.	9.4	5.2	0.6

a. PE = Thornthwaite's Precipitation Evaporation Index (see Table 4-5).

Table 4-5. 1975 Precipitation Evaporation Index for Phoenix Area

Month	P_{1974}	t_{1974}	$\frac{P}{e}$ 1974	P_{1975}	t_{1975}	$\frac{P}{e}$ 1975	$(PE)_{1975}$	1975 Quarterly PE Average
1				.02	52.3	0.0	8.8	8.8
2	.02	56.7	0.0	.33	54.0	0.1	9.3	
3	1.37	64.5	0.2	.63	59.0	0.1	8.3	
4	.01	70.6	0.0	.43	62.6	0.1	8.8	8.8
5	.00	80.2	0.0	.00	76.7	0.0	8.8	
6	.00	92.2	0.0	.00	86.6	0.0	8.8	
7	.84	92.4	0.1	.38	94.3	0.1	8.4	7.7
8	1.15	91.2	0.1	.00	91.9	0.0	7.4	
9	1.07	87.2	0.1	.82	86.2	0.1	7.2	
10	2.12	75.9	0.3	.23	72.9	0.1	4.9	5.3
11	.44	61.5	0.1	.55	60.9	0.1	5.1	
12	.59	50.6	0.1	1.12	54.8	0.2	5.9	

Notes:

1. $\frac{P}{e} = 11.5\left(\frac{P}{t-10}\right)^{\frac{10}{9}}$ where p - monthly rainfall in inches, t = temperature in °F. $\frac{P}{e}$ is precipitation evaporation ratio.
2. $PE = 10\sum_{n=1}^{12}\left(\frac{P}{e}\right)_n$ where PE = Thornthwaite Precipitation Evaporation Index.
3. PE historical = 9.4

The unsheltered distance factor for a given road surface in the prevailing wind direction varies continually. To assess an average effective distance factor, it was assumed that in the long-term, wind direction is equally distributed for all roads. Any error attributable to this assumption would be minimized by the more probable assumption that unpaved dirt roadways are equally distributed in terms of direction. For example, when the prevailing wind traverses north-south roadways at a 10° angle, it must in turn traverse all the east/west roads at an 80° angle. The net effect is to balance the various cases of wind directions oblique to the road. Figure 4-7 shows the effect of wind direction to unsheltered road distance for an average unpaved road in the Phoenix area. Figure 4-8 relates the unsheltered distances to the unsheltered distance factor L'. L' is related to the distance in which maximum soil movement is reached, and varies with soil erodibility. For an equally distributed wind direction, the average value of L for road surfaces of specified erodibility IK, are shown in Table 4-6. It is evident that L' varies only slightly for the range of soil surfaces to be considered in the Phoenix area.

Table 4-6. Unsheltered Road Distance Factor L'

IK	L' at Different Prevailing Wind Directions				Average L'
	$\theta = 90°$	$\theta = 60°$	$\theta = 30°$	$\theta = 0°$	
10	.01	.01	.01	1.00	.26
40	.05	.06	.07	1.00	.29
60	.08	.09	.10	1.00	.32

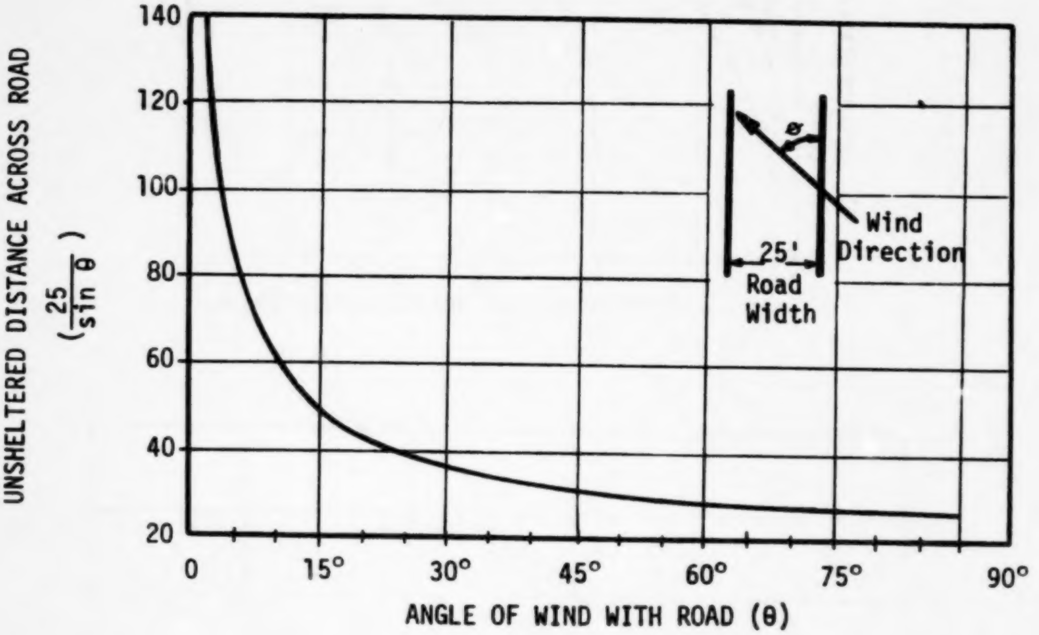


Figure 4-7. Effect of Wind Direction on Unsheltered Road Distance

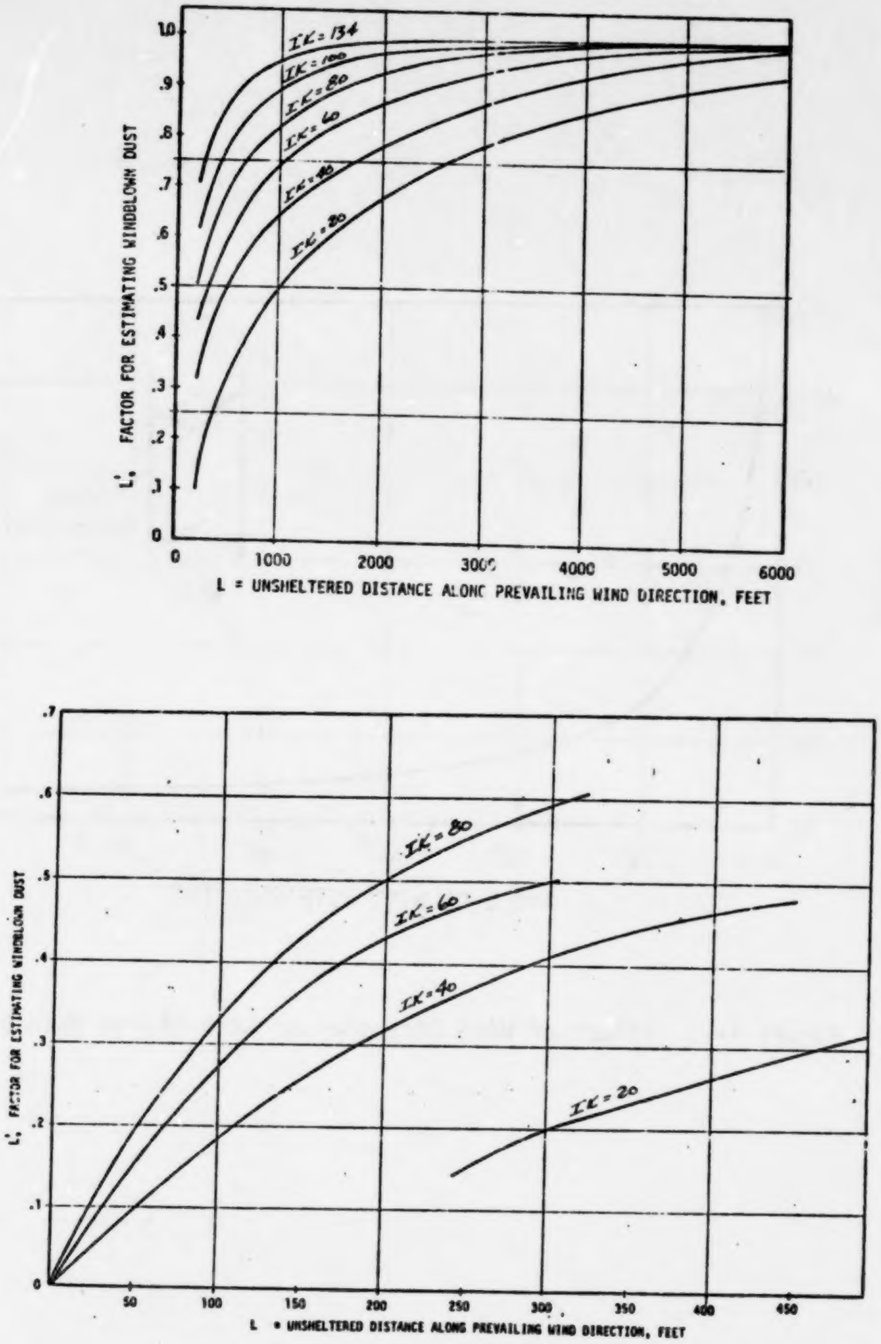


Figure 4-8. Effect of Unsheltered Field Length on Relative Emission Rate [1].

Emission Estimates

Estimates of suspended dust arising from wind over unpaved dirt roads were calculated by assigning specific values discussed previously to the parameters of the wind erosion equation. A suspension factor of .038 was applied to approximate the suspended portion of the wind erosion soil losses. Table 4-7 summarizes the overall computation procedure. The emissions are computed on a seasonal basis to reflect the significance of differences in the climate.

Figure 4-9 illustrates the gridded emission inventory for windblown fugitive particulate emissions off unpaved roads. The magnitude of emissions for each of the 2 km grid squares is given by a single digit number representing an emissions regime as shown by the accompanying grid legend. As indicated, the magnitude of windblown dust from unpaved roads is relatively insignificant. An emissions grid was developed for each of the seasons, and demonstrated the following variation for 1975:

Quarter	tons/day
1	1.4
2	2.1
3	2.7
4	3.8
Average	2.5

It should be remembered that the seasonal variation of climate in 1975 was appreciably different than the historical average, and that any given year is likely to show a unique variation in windblown roadway emission levels. Also, because windblown emissions are related to the cube of wind speed, it is evident that short term wind blown dust levels may exceed the amount shown above by several times during gusty winds.

The distribution of emissions resulting from windblown roadway dust is illustrated graphically in Figure 4-10. As expected, the areas generating the greatest levels of roadway dust are in the immediate neighborhood surrounding urban Phoenix, as well as in the surburban and remote areas to the northwest and south. The distribution remains unchanged by season, since climate has been assumed homogeneous over the entire study area. It should be clear however, that short term spatial variations in climatology would affect the distribution of Figure 4-9 significantly.

Table 4-7. Wind-Blown Fugitive Emissions Off Unpaved Roads in the Phoenix Area, 1975

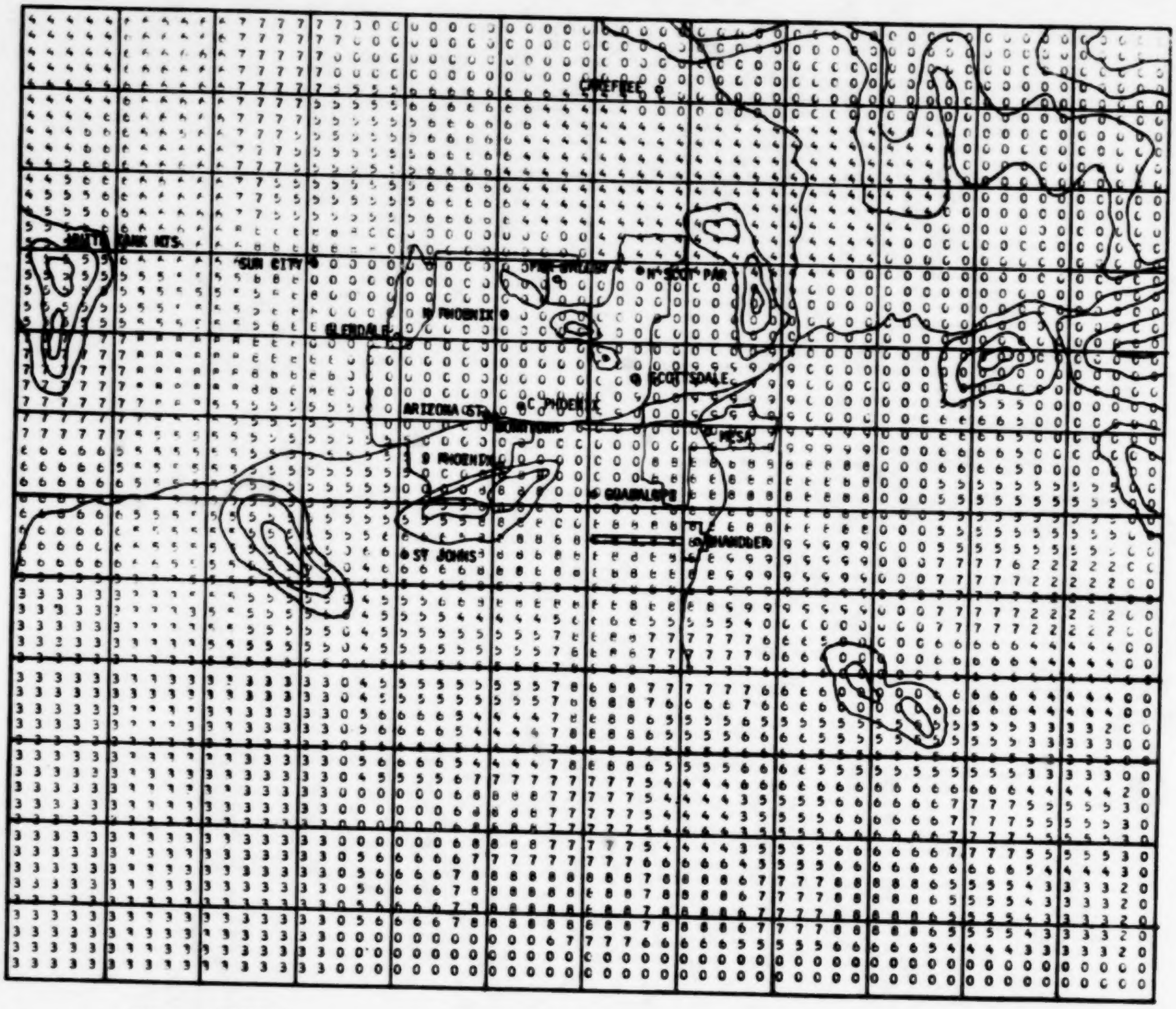
Specific Area (Maintenance area or township)	D, Miles of Dirt Roads	Basic Erodibility, I, of Soil, (ton/acre/year)	Unsheltered Distance Factor, L'	Emissions = AIKCL'V'(D)(.00828) tons/day			
				1st Quarter E=.00543IL'D	2nd Quarter E=.000912IL'D	3rd Quarter E=.0015IL'D	4th Quarter E=.0015IL'D
-	a	b	c	d	d	d	d

a See discussion of Section 3.1.2.

b Derived from soil silt content and Figure 4-6.

c Determined from Table 4-6.

d Computed from the wind erosion equation and the suspension factor .038. K = 1, V' = 1, and the climatic factor C is calculated for each season (Table 4-4).


WHITE TANK MTS.
CAREFREE
SUN CITY
PARADISE VALLEY
N SCOT PAR
N PHOENIX
GLENDALE
SCOTTSDALE
ARIZONA ST
C PHOENIX
DOWNTOWN
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY	
0	0	to 0
1	0	to .00001
2	.00001	to .00007
3	.00007	to .00021
4	.00021	to .00052
5	.00052	to .0010
6	.0010	to .0019
7	.0019	to .0034
8	.0034	to .0055
9	.0055	to .0083

Figure 4-9. Particulate Emissions Grid for Wind Blown Dust off Unpaved Roads, Fourth Quarter, 1975.

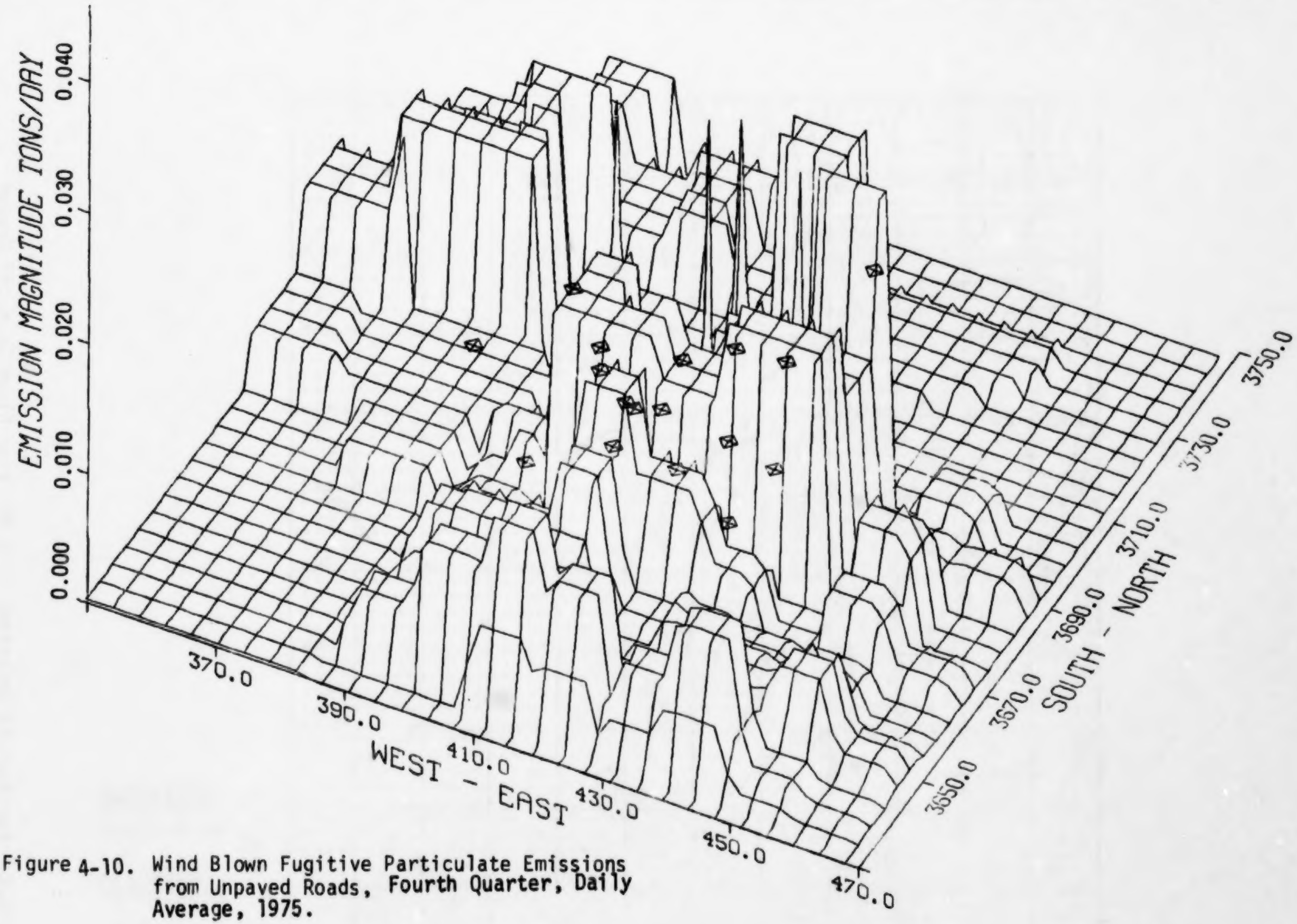


Figure 4-10. Wind Blown Fugitive Particulate Emissions from Unpaved Roads, Fourth Quarter, Daily Average, 1975.

The particle size distribution of the suspended dust was approximated based on two considerations. The first is Gillete's finding [7] that suspended aerosol distributions approximate the particle size distribution of the parent soil and are independent of wind speed for particle diameters 20μ or less. Second is the assumption that at average wind speed 7.8 mph (1975 Phoenix average), particles greater than 30μ will not be suspended or will settle quickly (see Figure 4-4). Table 4-8 shows the average distribution of particle sizes estimated for windblown dust from unpaved roads.

TABLE 4-8. Particle Size Distribution of Suspended Soil Losses from Unpaved Roads (1975)

Particle Size Range (diameter)	Percentage of Soil Particles by weight in native soil[a]	in suspended soil losses
< 2μ	6%	21%
2μ to 20μ	15%	54%
20μ to 30μ	7%	25%

[a] While it was shown that the silt content of unpaved road surfaces was unlike that of the native soils, no specific data was available to define the distribution among those particles assumed suspendable by wind (0 to 30μ). It was assumed that the weight distribution of the suspendable particles could be approximated closely by the relative distribution of these particles in the native soil. The native soil was considered to consist of two predominant soil types (see Section 3.6).

4.3 WINDBLOWN EMISSIONS OFF AGRICULTURAL FIELDS

Except for the region to the North and Northeast, the Metropolitan Phoenix Area is surrounded by agricultural croplands. These lands comprise an estimated 1450 square miles including a portion of Pinal Colony in the project study area. Soils of these lands are variable, and range in silt content (<75μ) from about 20 to 70%. Mechanical disturbance of these soils through agricultural activities contributes to the disaggregation of the soils, tending to make them more susceptible to drifting by wind. In addition, dry climate and high temperatures contribute substantially to soil errodibility. The suspension of soil particles during periods of maximum soil erosion may cause significant impact on particulate levels throughout the Metropolitan Phoenix Area. The following discussion provides a review of previous wind blown agricultural emissions, a description of the methodology utilized for the present emission inventory, and a summary of agricultural emissions estimates derived for this study.

Review of Previous Inventories

Only the PEDCo investigation has considered wind blown soil emissions from agricultural fields. In that study dust emissions from agricultural fields were estimated by employing the wind erosion equation. A 2.5% suspension of the soil erosion losses was assumed. These calculated dust emission rates were compared to rates calculated by solution of Pasquill-Gifford diffusion equations (ground level sources with no effective plume rise) using measured particulate concentrations in agricultural fields. Based on the final report [2], it is unclear if results of these approaches were consistent. However, because the wind erosion equation approach accounts for a variety of different crop situations, the equation was employed by PEDCo to estimate 1970 agricultural emission sources in the Phoenix area. Crop data was obtained to assess the specific emission totals associated with the various major crop type.

A specific limitation of the previous study was the climatic factor due to seasonal and historical variations, and irrigation practices. Irrigation results in maintenance of soil moisture, and the consolidation of the soil. Depending on the crop, irrigation requirements vary from about 25 inches of equivalent rainfall to 74 inches. This irrigation exerts a substantial effect on the year-long aggregation of agricultural soils. The irrigation moisture for the various crop is reflected dramatically by the corresponding value of the climatic factors. The factors are several times less than that for non-irrigated lands experiencing only the native moisture levels (as will be shown in following sections). Therefore, neglecting the effect of irrigation on agricultural soil losses has probably resulted in emission estimates which were substantially overstated in the previous inventory.

The variation of wind speed is another important determinant to the year-long or seasonal levels of soil wind erosion losses. Area-specific wind speeds occuring in the baseyear for the study should be used to estimate specific emission levels for that year. Long-term historical averages which are only region-specific are not representive of base year emissions, and limit the credibility of source=receptor relationships which employ base-year air quality data for calibration.

Methodology of the Present Inventory

Wind blown dust emissions from agricultural fields were estimated by assigning area specific values to the variables of the MRI form of the wind erosion equation (Section 4.2). Except for the potential soil errodibility I, the emission determinants depend on crop type. In the process of the development of the wind erosion equation, the U.S. Department of Agriculture has assembled sufficient data to parameterize soil surface preparations and agricultural practices for various crops. These data will be employed to estimate crop specific soil losses in each township of the study area.

An average value for the soil errodibility I, was determined for the agricultural area of each township of the study area. Soil silt measurements by the U.S. Department of Agriculture [5] were related to soil types identified on general soil maps [6]. Agricultural regions were then located on the soil maps with the use of aerial photographs [10]. An average silt content was estimated for cropland within each township by weighting township cropland acreage and corresponding soil silt levels. Average errodibility of the croplands was then determined by the silt content/errodibility relationship shown in Figure 4-6 (the fraction of soil particles <.84μ was assumed to approximate that fraction <.75μ as available from USDA silt measurements [5]). The soil errodibility was found to vary from

2 to 55 tons/acre-year among the townships. This variation is substantial and would cause significant local variations in windblown dust levels from agricultural fields.

Values for the soil surface roughness factor K, the unsheltered field length L, and the vegative cover, are relatively uniform for a specific crop. The surface roughness factor accounts for resistance to wind erosion due to ridges or clods in the field. An optimal ratio of ridge heights to ridge spacing will reduce soil erosion by a factor of .5. Table 4-9 shows typical roughness factors associated with soil preparation for various crops.

Average field sizes for relatively flat terrain devoid of tall natural vegetation have been established for various crops as shown in Table 4-9. Soil losses from wind erosion accross a field vary from the windward edge of the field and increase proportionately with length until a terminal rate of soil movement is attained. The distance required before attaining maximum erosion rate is influenced by the potential errodibility (I) and roughness (K) of the soil. The relationship between the unsheltered field length (L), the surface erosion potential IK, and the field length factor L' is shown in Figure 4-8.

The amount of vegative cover residue left on a field after the growing season varies appreciably by crop (Table 4-9). Cover residue reduces soil wind erosion losses by the factor V' as shown in Figure 4-11. The degree of reduction attainable with crop residue is related to the value of IKCL'.

Five major crops comprised about 94% of all agricultural land use in 1975. Table 4-10 shows the extent of acreage used for each of the crops. During the growing season, wind erosion losses from soil under these crops is assumed to be negligible except for lands growing cotton. Cotton provides only minimal cover for the land leaving the soil susceptible to erosion throughout the year. Alphalfa on the other hand, provides sufficient cover during and after the growing season to deter soil erosion to negligible levels.

TABLE 4-9. VALUES OF K, L AND V FOR COMMON FIELD CROPS [1]

Crop	K	L,ft.	V,lb/acre
Alfalfa	1.0	1000	3000
Barley	0.6	2000	1100
Beans	0.5	1000	250
Corn	0.6	2000	500
Cotton	0.5	2000	250
Grain Hays	0.8	2000	1250
Oats	0.8	2000	1250
Peanuts	0.6	1000	250
Potatoes	0.8	1000	400
Rice	0.8	1000	1000
Rye	0.6	2000	1250
Safflower	1.0	2000	1500
Sorghum	0.5	2000	900
Soybeans	0.6	2000	250
Sugar Beets	0.6	1000	100
Vegetables	0.6	500	100
Wheat	0.6	2000	1350

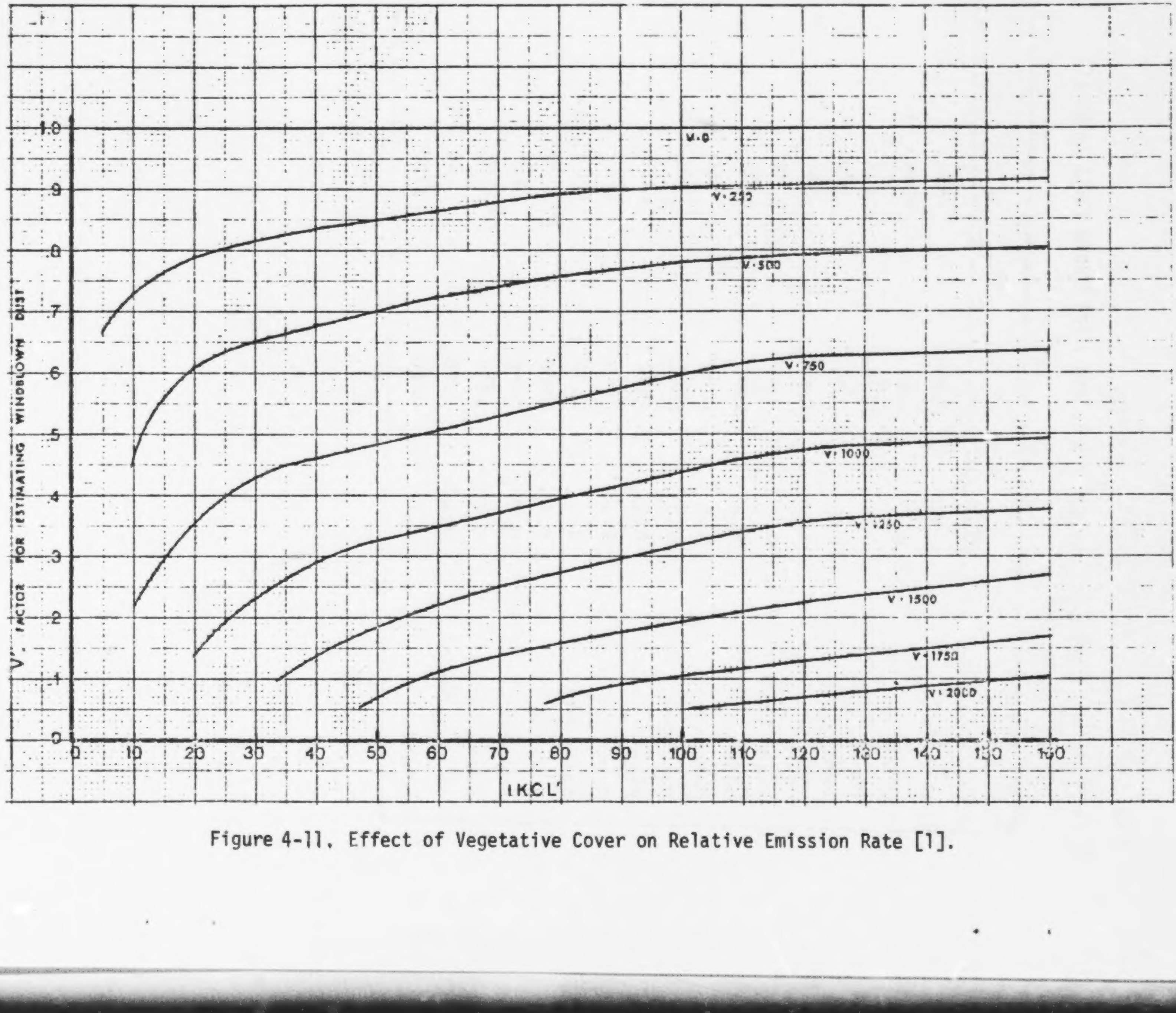


Figure 4-11. Effect of Vegetative Cover on Relative Emission Rate [1].

TABLE 4-10. MAJOR CROPS IN PHOENIX STUDY AREA

CROP TYPE	AREAS OF CROPLAND*	PERCENTAGE OF TOTAL CROPLAND
Cotton	296,000	40.7
Alphafa and Hays	125,100	17.2
Barley	85,500	11.8
Sorghum	45,650	6.3
Wheat	128,600	17.7
Other	45,350	6.2
TOTAL	726,350	

* Reference [10] and [11].

Typical crop parameters (Table 4-9) were assigned to the five major crops grown in the study area. Since there were no apparent patterns involving crop spatial distribution, the study area crop distribution by township was assumed to be constant for both the Pinal and Maricopa County portions of the study area.

The climatic factor C, was calculated to reflect seasonal variations in temperature, soil moisture (including precipitation and irrigation effects) and average wind speeds for the study area in the 1975 baseyear. Consideration for these specific variations has obvious implications for the soil erosion estimates. Values of C are unique for the study region, and vary significantly by season and crop type. Values of C for the study area by season were derived in Section 4.2. To calculate wind blown soil losses from agriculture fields, these values were adjusted to reflect additional soil moisture provided by crop irrigation.

Figure 4-12 illustrates approximate water use requirements for cotton crops in the study area. A total of 41 inches of water is provided during the growing season on a schedule peaking in August. Additional water (about 20 inches) is supplied for other reasons than consumptive use by the crop (for leaching salts, softening a crust, moving fertilizers into soil, compensation for runoff losses, etc.). The effect which these irrigation waters exert on soil moisture, and the manner in which this may be related to the precipitation evaporations is not clear. Surely irrigation water on cropland soils will not produce as great an effect on the soil moisture as an equivalent amount would on soil supporting less vegetation. Consumptive use of the water by plants will account for much of the water use. Also, the irrigation schedule applies to the growing season, not the period when the soil is most susceptible to wind erosion. On the other hand, periodic irrigation during the growing season does maintain the soil moisture and aggregated state of the soil. The effects of the irrigation are significant in the non-growing season, when disconsolidation of the soil and exposure to winds would reduce resistance to soil erosion. In the absence of available guidelines, it was assumed for the purposes of this study that irrigation water use could be related to soil moisture in the same manner as rainfall in the precipitation evaporation index. However, only the minimal crop water use, as shown in Figure 4-12 was incorporated to calculate the adjusted PE values.

Based on area-specific irrigation schedules for the five major crops, and monthly precipitation and temperature data, a PE index was calculated for each crop. The PE values were then combined with 1975 quarterly average wind speeds to calculate quarterly climatic factors for each crop. The results of these calculations are shown in Table 4-11.

TABLE 4-11. CROP-SPECIFIC CLIMATIC FACTORS

CROP	PE INDEX	AVERAGE CLIMATIC FACTOR $C = .345 \frac{W^3}{(PE)^2}$			
		1st quarter	2nd quarter	3rd quarter	4th quarter
Cotton	58.0	.04	.06	.06	.04
Alphalfa	113	.01	.02	.02	.01
Barley	52.8	.05	.07	.07	.05
Sorghum	40.2	.08	.13	.12	.08
Wheat	54.9	.04	.07	.07	.04

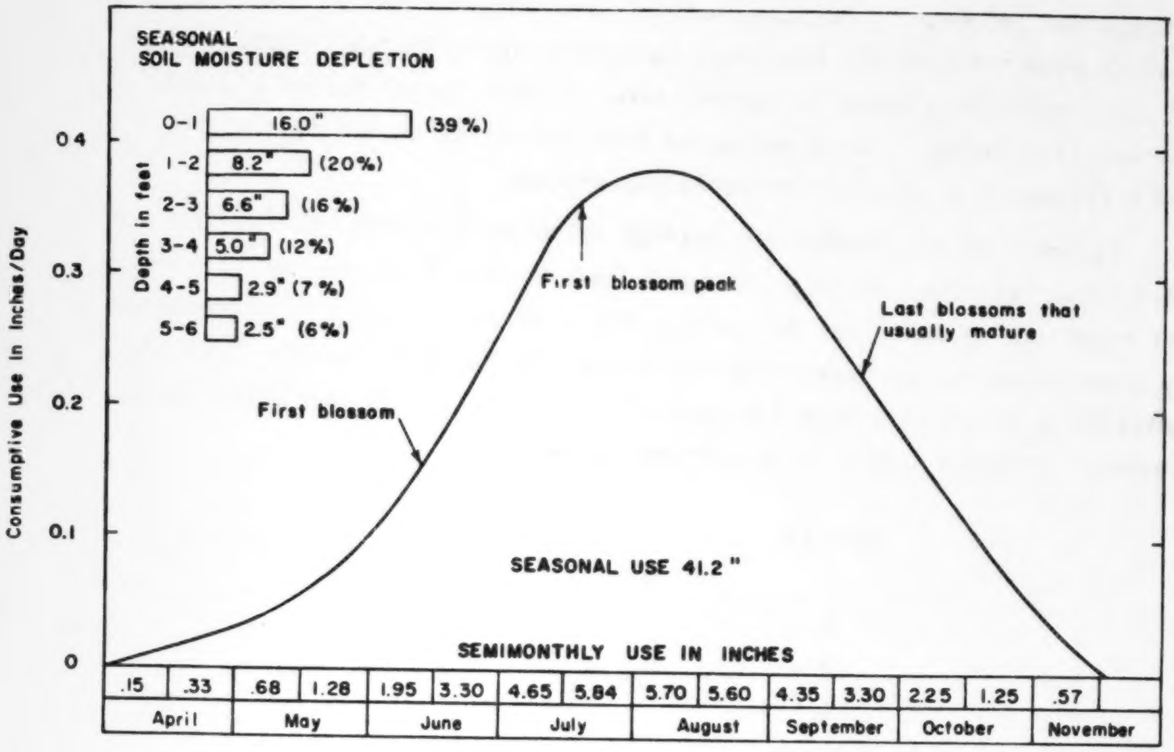


Figure 4-12. Mean Consumptive Use of Water by Cotton at Mesa, Arizona, 1954-1962 [12].

Emission Estimates

Estimates of suspended dust arising from soil wind erosion losses were calculated based on assignment of wind erosion equation parameters as specified previously. A suspension factor of .025 was employed to approximate the suspended portion of the soil losses. Table 4-12 summarizes the overall computation procedure. The calculations were computerized for convenience in dealing with the numerous townships containing agricultural fields. Values of the errodibility index I, the unsheltered field length factor L', and the vegative factor V' were extracted from the curves of Figure 4-6, 4-8, and 4-11 through a software interpolation program.

Figure 4-13 illustrates the gridded emission inventory for fugitive wind blown emissions over agricultural lands in the first quarter of 1975. The magnitude of emissions for each of the 2 km grid squares is represented by a emissions regime rank number as defined by the grid legend. Such an emission grid was developed for each of the seasons. The variation in seasonal emission levels is summarized below:

QUARTER	TONS/DAY
1	4.1
2	4.0
3	3.8
4	4.0
Average	4.0

The variation is less significant than might be expected due to the fact that the cotton crop, which is assumed susceptible to wind erosion throughout the year, dominates the emissions total.

The distribution of emissions arising over agricultural lands is illustrated graphically in Figure 4-14. The substantial portion of the wind blown emissions originate southeast of Phoenix. The prevailing direction of gusty winds (during the thunderstorm season) is also from the southeast. Since windblown emissions increase with the third power of wind velocity, it appears that agricultural wind blown soil dust could exert a significant impact on dust levels in Phoenix during windy conditions. The distribution represented in Figure 4-14 remains relatively constant by season, since it has

TABLE 4-12. COMPUTATIONAL PROCEDURE FOR ESTIMATION OF FUGITIVE DUST FROM WIND EROSION OF CROPLANDS IN FIRST QUARTER[e].

$$E = .025\ GIKC_1L'V'f$$

		G	I	K	C_1	L	L'	V	V'	f	
TOWNSHIP	CROP TYPE	ACRES OF CROPLAND	SOIL ERRODIBILITY (tons/acre-yr)	SURFACE ROUGHNESS FACTOR	CLIMATIC FACTOR FOR 1st QUARTER	UNSHELTERED LENGTH (ft)	LENGTH FACTOR	VEGETATIVE RESIDUE (lb/acre)	VEGETATIVE FACTOR	FRACTION OF YEAR FOR WHICH SOIL IS EXPOSED IN QUARTER[d].	TOTAL EMISSIONS Tons/Quarter
-	Cotton	-	a.	.5	.04	2000	b.	250	c.	3/12	-
	Barley	-	↓	.6	.05	2000	↓	1100	↓	0	-
	Sorghum	-	↓	.5	.08	200	↓	900	↓	3/12	-
	Alphafa	-	↓	1.0	.01	1000	↓	3000	↓	0	-
	Wheat	-	↓	.6	.04	2000	↓	1350	↓	0	-

a. Values of I are determined from silt content and Figure 5-3.

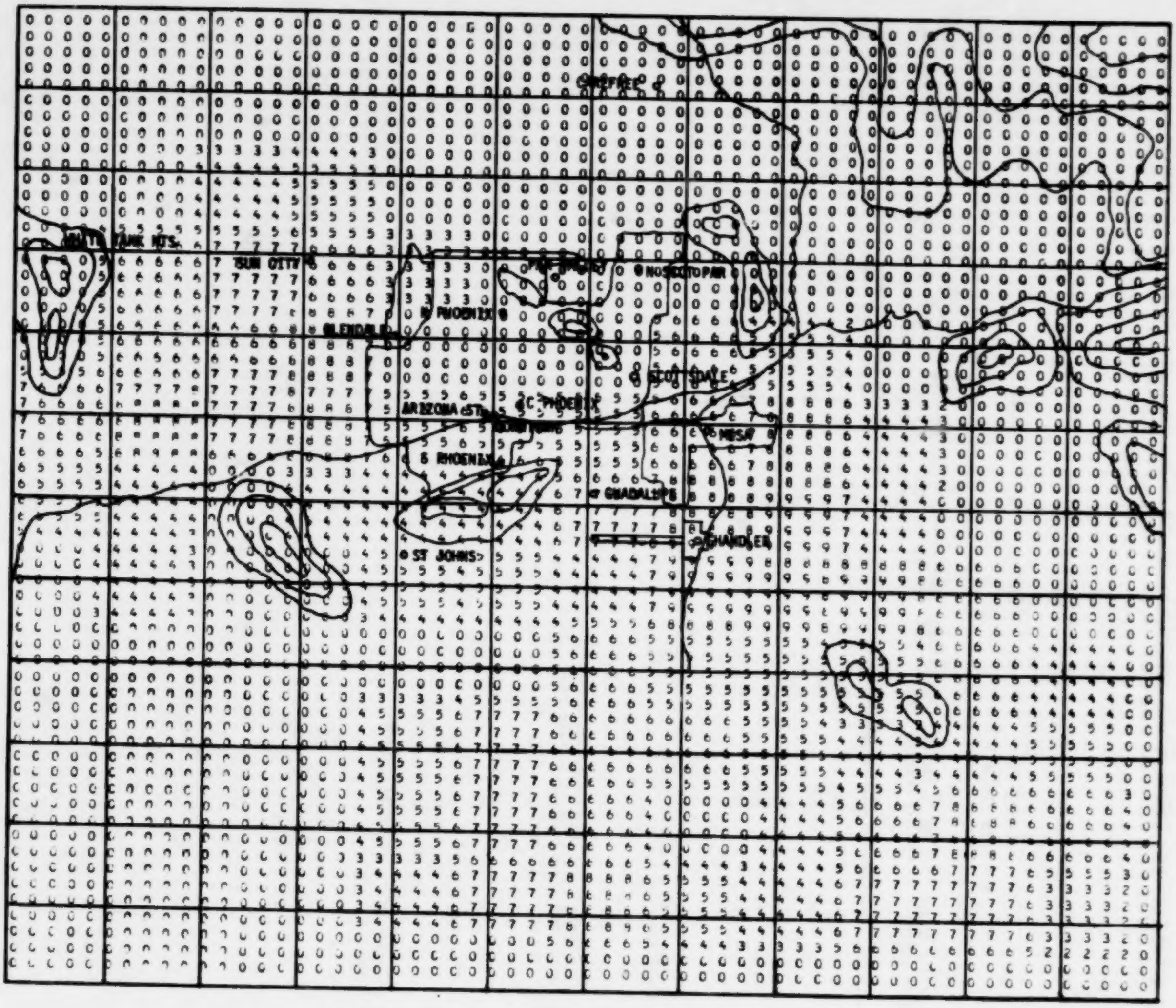
b. L' is determined from IK and Figure 4-8.

c. V' is determined from ICCL' and Figure 4-11.

d. The period of soil exposure is equivalent to non-growing season for grain crops, and assumed to exist throughout the year for cotton crops due to limited soil cover provided by cotton vegetation. The exposure periods are:

- cotton, throughout the year
- barley, May to Decmeber
- sorghum, November to July
- alphalfa, no period
- wheat, May to December

e. To calculate emissions for remaining quarters of 1975, the procedure above is repeated using appropriate values for c and f.


WHITE TANK MTS.
SUN CITY
GLENDALE
N PHOENIX
NOSECOTOPAR
SCOTTSDALE
C PHOENIX
ARIZONA ST.
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	.00000 TO .00000
1	.00000 TO .00002
2	.00002 TO .00009
3	.00009 TO .0003
4	.0003 TO .0007
5	.0007 TO .0015
6	.0015 TO .0028
7	.0028 TO .0048
8	.0048 TO .0078
9	.0078 TO .012

Figure 4-13. Particulate Emissions Grid for Wind Blown Dust off Agricultural Fields, Third Quarter, 1975.

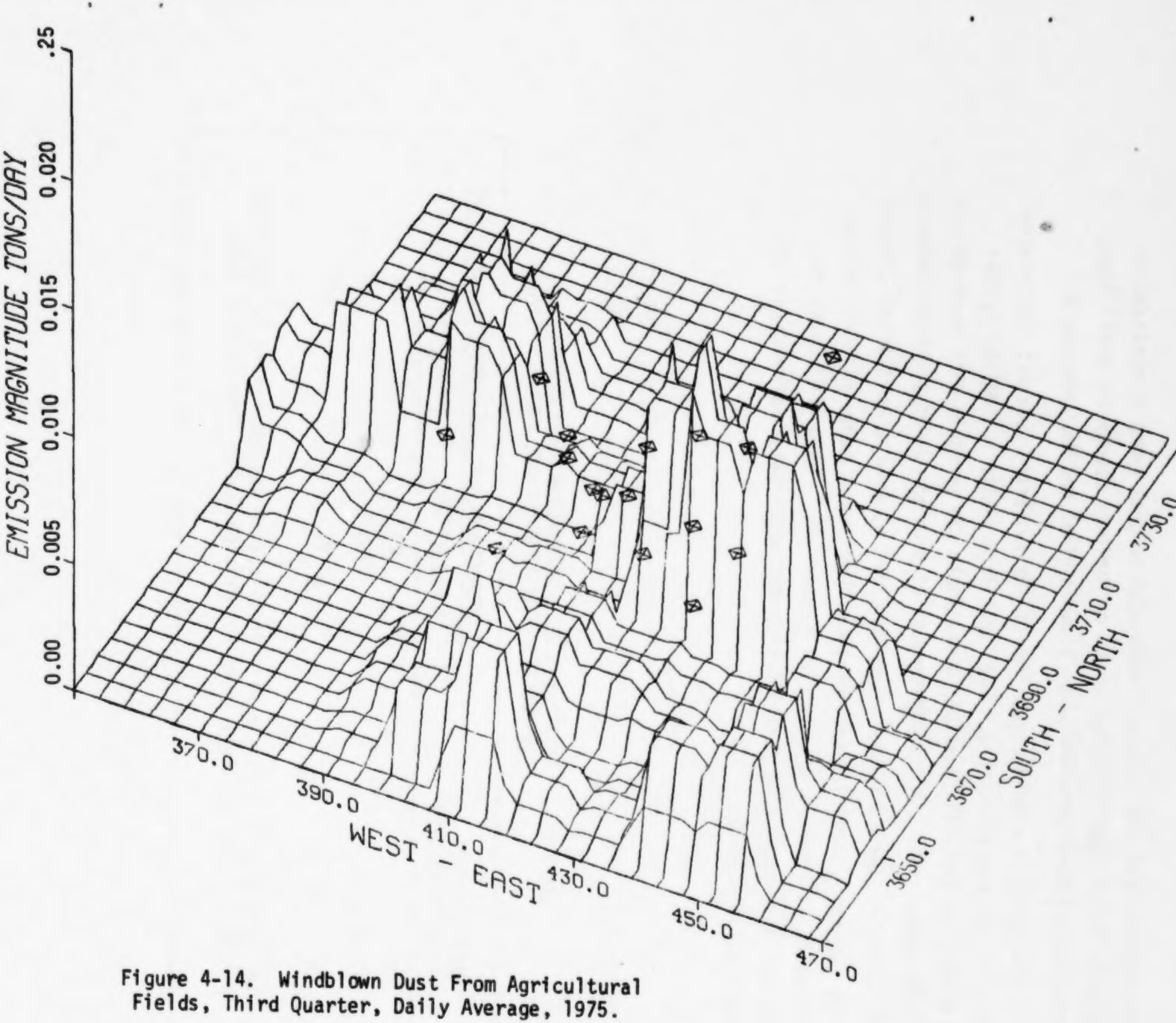


Figure 4-14. Windblown Dust From Agricultural Fields, Third Quarter, Daily Average, 1975.

been assumed that the relative proportion of crop types is constant by township for the two contained areas of Maricopa County and Pinal County (only the relative emission level between Pinal and Maricopa varies).

The particle size distribution of the suspended dust was approximated based on two considerations. The first is Gillette's finding [7] that suspended aerosol distributions approximate the particle size distribution of the parent soil and are independent of wind speed for particle diameters 20μ or less. Second is the assumption that at wind speed 7.8 mph (Phoenix 1975 average), particles greater than 30 micron diameter will not be suspended or will settle quickly (see Figure 4-4). Table 4-13 shows the average distribution of particle size estimated for windblown dust off agricultural fields.

TABLE 4-13. PARTICLE SIZE DISTRIBUTION OF SUSPENDED SOIL LOSSES FROM AGRICULTURAL FIELDS (1975)

PARTICLE SIZE RANGE (DIAMETER)	PERCENTAGE OF SOIL PARTICLES BY WEIGHT	
	IN PARENT SOIL[a]	IN SUSPENDED SOIL LOSSES
<2	6%	21%
2μ to 20μ	15%	54%
20μ to 30μ	7%	25%

a. The average soil particle size distribution was determined by averaging the two predominant soil types in Maricopa County (see Section 3.6).

4.4 WIND BLOWN EMISSIONS OFF UNDISTURBED DESERT

Approximately 30% (1650 square miles) of the study area is comprised of undisturbed desert pavement. Most of this land is concentrated to the north and south of Phoenix. The soil surface of undisturbed desert displays a crusty surface including many pebbles, and generally supports a variety of desert scrub, creosote, and cactus. The crust of the desert pavement is relatively resistant to wind erosion, although this resistance may vary significantly during the year. Exposure of the crust to the sandblasting effect caused by winds tends to disturb the consolidation of the surface, while precipitation tends to restore the crust. Only very limited attention has been directed to the understanding of this behavior. Consequently, the methodology established in the following sections for the estimation of wind blown soil from the desert floor is subject to appreciable uncertainty.

Review of Previous Emission Inventories

None of the previous emission inventories developed for the Phoenix area have included an estimate of fugitive dust loadings off the undisturbed desert. The basis of this omission in previous work is not clear. It was probably considered that fugitive dust arising from the stable desert pavement would not be a significant contributor to dust levels. This assumption is undoubtedly correct for periods of low wind speeds. However, as shown in the air quality review of this project [13], increasing wind speeds result in high levels of suspended particulates in environments adjacent to appreciable segments of undisturbed desert. Because of the broad expanses of land comprising this fugitive source, it is appropriate to address the significance of its emission strength.

Methodology for Present Inventory

The most apparent relevant study characterizing fugitive dust emissions from undisturbed desert is described by Shinn [8]. The Shinn model, discussed in Section 4.1, describes vertical flux of soil particles from a desert pavement as a function of wind velocity. The model, based on field measurements of dust loadings from desert (Nevada) very similar to the Arizona desert, appears to express unreasonably high values of suspended soil particles (see Table 4-2). As discussed previously, the highest estimates may be due to the influence of local source influences dominating the dust loadings. Another model similar to the Shinn version, proposed by Gillette [23], expresses the vertical flux F as

$$F = k\left(\frac{u}{u_{thresh}}\right)^{\gamma} \quad \text{for } u > u_{thresh}$$

$$= 0 \quad \text{for } u < u_{thresh}$$

In this version, $\gamma > 3$. The value of γ increases with silt per unit mass content of the soil. The threshold friction velocity varies for different soils and surface roughness ratios, but was found to be approximately .6 mph (corresponding to a wind speed of about 6 mph) for the conditions supporting derivation of the model. Unfortunately the characteristics of the soils tested by Gillette were dissimilar to conditions of the Arizona desert. The field sites were Texas agricultural fields, exhibiting relatively high soil silt contents, while the Arizona desert pavement demonstrates a relatively low silt content and a crusted surface. A third model, developed by MRI [9], combines elements of the wind erosion equation and the Gillette findings to relate wind blown soil dust to soil and site characteristics, and the duration of time which the threshold wind speed is exceeded. This model is derived from a synthesis of field data, none of which bear similarity to Arizona desert environments.

Clearly, the research is presently too narrow in scope to utilize parametrized relationships such as the Gillette model. The MRI model appears to yield reasonable estimates of suspended soil loadings, but does not account for the impact of increasing velocities on vertical flux. When compared to Gillette test data, the MRI model estimates are consistent with the apparent pattern that the fraction of horizontal soil flux which is suspended increases with decreasing horizontal flux. However, at higher wind speeds, the MRI model will not conform to this pattern. It may be plausible therefore to utilize estimates calculated by the MRI model to establish parameterization of the Gillette model at wind speeds near the threshold value, and to employ the Gillette model to describe soil emissions associated with the higher end of the wind speed distribution. This approach is, however, similar to utilization of the wind erosion equation, which also assumes a third power term of wind velocity. Because it is at present unclear which of these approaches would yield best results, it was concluded that estimations of wind blown desert soil would be derived employing the wind erosion equation (in combination with a suspension factor). This approach is consistent with those estimations derived for other fugitive source categories (i.e., wind blown dust off unpaved roads) identified in the study.

Wind blown suspended dust off the desert pavement was estimated by the adapted and simplified form of the wind erosion equation discussed in Section 4.1. This form, including the suspension factor of .018, is

$$E = .018\ IKCL'V'.$$

The soil errodibility index (I) for typical soil of the Arizona desert was approximated by assuming it equivalent to that of the Nevada desert surface, which has been sampled and analyzed by Shinn [8,15]. A sample of the surface soil indicated an average silt content of about 30% (percentage of particles $< 84\mu$). This corresponds to an errodibility index of 10 ton/acre/yr. A further adjustment of the index to reflect surface consolidation, or crust, indicates an errodibility of 1.67 ton/acre/year is the appropriate effective index to be applied in the calculations [14].

The climatic factor C was calculated to reflect seasonal variation in temperature, precipitation, and average wind speeds for the Phoenix area. These computations are discussed in Section 4-2 and summarized in Table 4-4. Due to lower than normal rainfall and higher than usual wind speeds, an unusual seasonal pattern for the climatic factor (C) was experienced in 1975.

The unsheltered distance factor for the undisturbed desert was assumed to approach unity since most of the desert area is subject to uninterrupted erosion for thousands of feet. The vegetation cover factor was presumed to be .9. The desert surface exhibits abundant scrub, but this growth is intermittent and actually covers a small fraction of the desert surface. The true effect of the desert growth on the vegetative factor is unclear, since empirical derivation of the factor is based on agricultural crop residues, quite unlike the desert type of growth. Selection of .9 as the vegetative cover will insure that the fugitive emission levels are not underestimated.

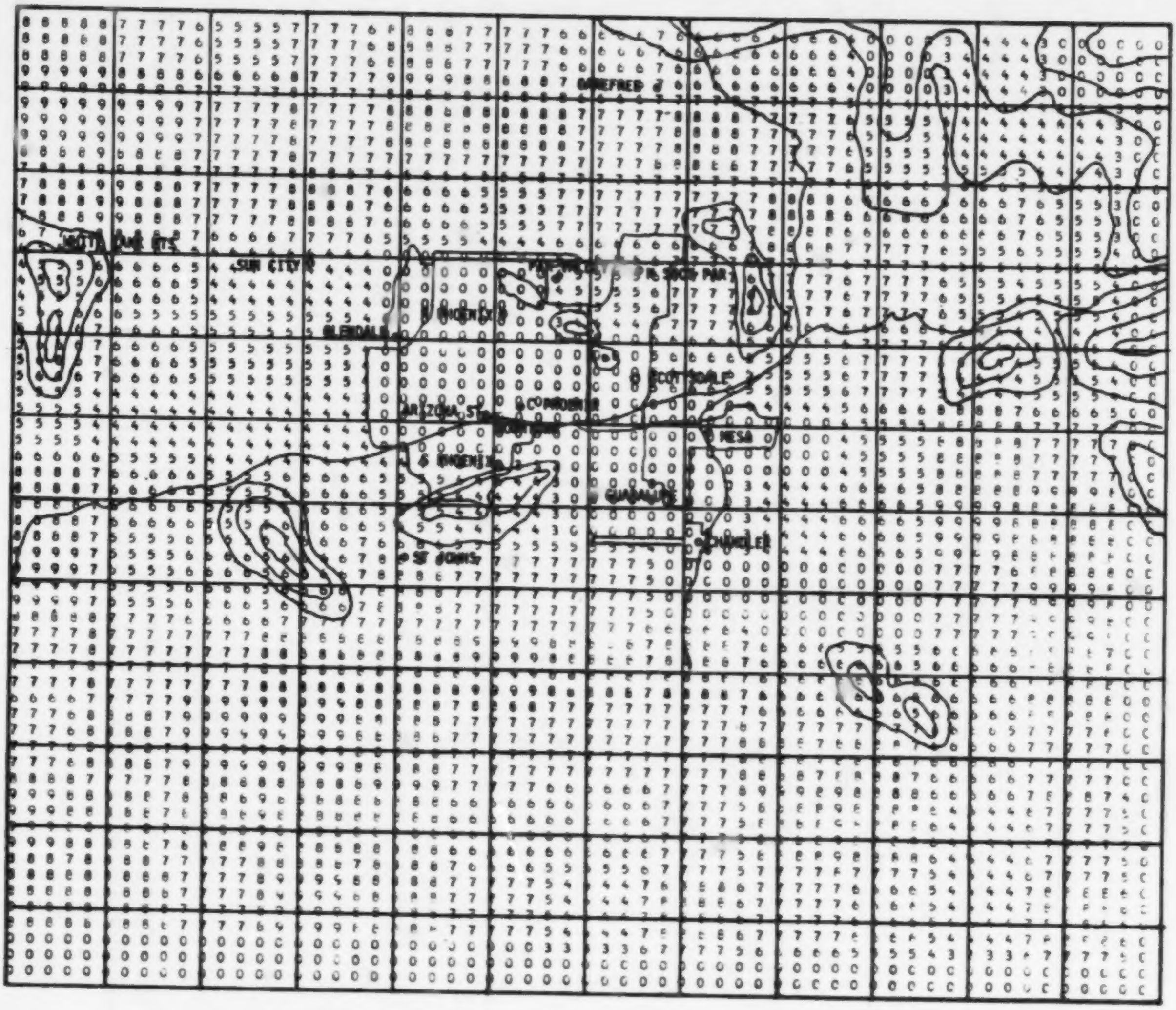
The amount of desert in each township was estimated using aerial photographs included in the Arizona Cropland Atlas [10], and a current land use map of the study area [18]. A software program developed for the study was employed to convert the township acreage to the grid cell network utilized for spatial expression of emissions levels.

Estimates of suspended dust arising from wind over the undisturbed desert were calculated by assigning the parameter values to the wind erosion equation. The seasonal wind blown desert emissions for 1975 is presented below.

Quarter	Tons/Day
1	160
2	244
3	321
4	450
average	294

Figure 4-15 illustrates the gridded emission inventory for wind blown fugitive desert dust. It is important to note that windblown emissions may exceed the amounts shown above by several times during gusty winds. The distribution of the desert soil emissions is illustrated in Figure 4-16. The desert areas generate large area sources of dust surrounding the Phoenix area, particularly to the north and south.

The particle size distribution of the suspended desert dust was approximated by assuming it to be equivalent to that of the parent soil for particle sizes 30 μ diameter or less. Disintegration of the soil aggregates by increased sandblasting of the surface causes the soil particles to exhibit the same aerosol distribution as if they had originally risen from a disturbed desert surface. Based on the


CAREFREE
WHITE TANK MTS
SUN CITY
GLENDALE
PHOENIX
SCOTTSDALE
ARIZONA ST.
MESA
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .001
2	.001 to .004
3	.004 to .01
4	.01 to .03
5	.03 to .06
6	.06 to .12
7	.12 to .20
8	.20 to .32
9	.32 to .49

Figure 4-15. Emissions Grid Map for Fugitive Dust Emissions Arising from Wind Erosion of Undisturbed Desert in Phoenix Area, First Quarter, 1975.

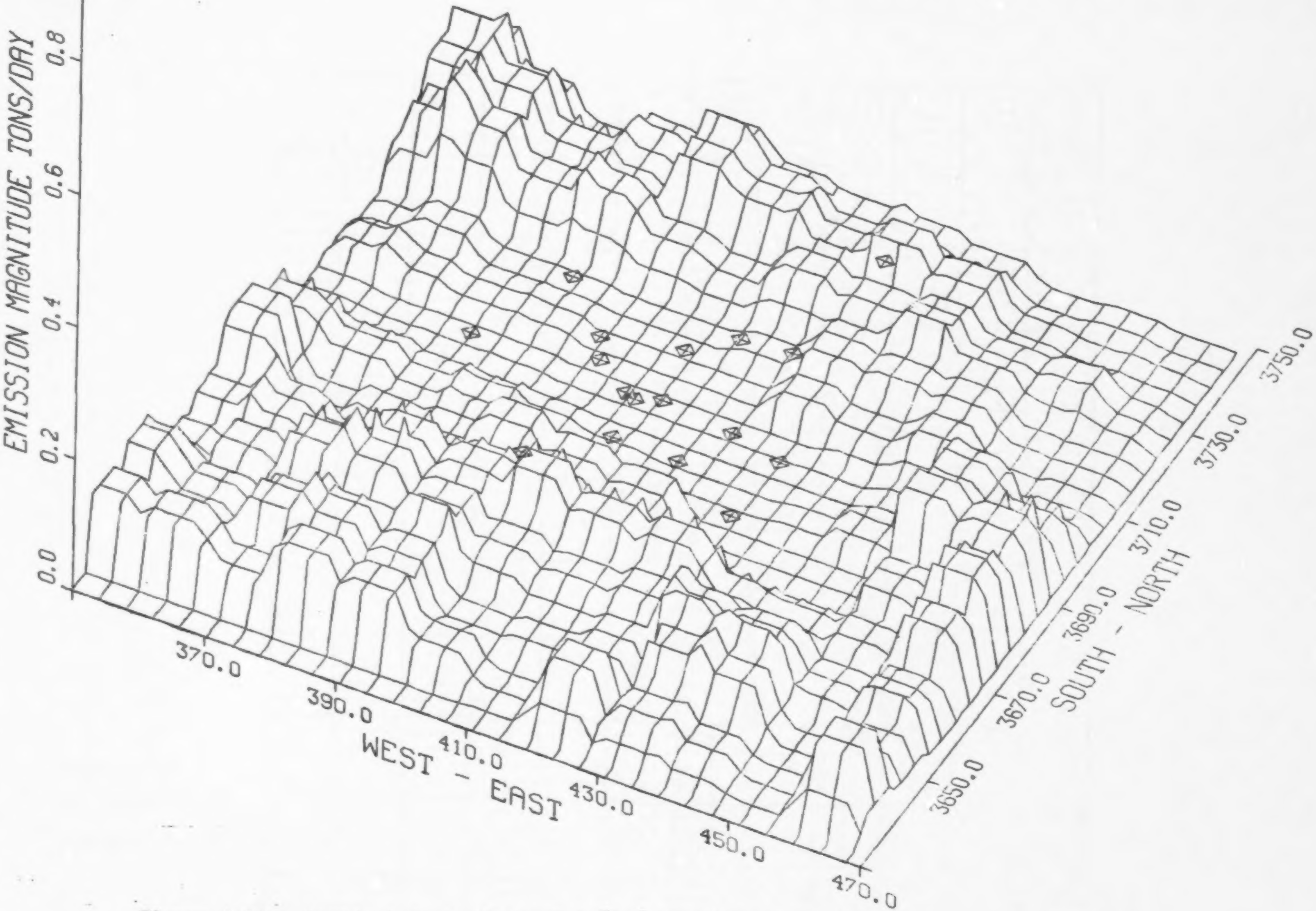


Figure 4-16. Particulate Fugitive Emissions Arising from Wind Erosion of Undisturbed Desert in Phoenix Area, First Quarter, Daily Average, 1975.

1975 average wind speed of 7.8 mph, the suspendable portion of the injected particles will be less than 30 μ in diameter. The expected aerosol distribution for $d < 30\ \mu$ was approximated from parent soil data (see Section 3-6) as follows:

< 2μ	21%
2-20μ	54%
20-30μ	25%

4.5 TAILINGS PILES

Tailings piles consist of deposits of earth removed during mining operations. For large mines, the tailing piles may expand over several thousand acres. Generally the piles are composed of substantial proportions of fines which are relatively susceptible to significant wind erosion losses. Fugitive emissions from tailings piles represent a minor source in the study area since few mining operations are conducted, and these are located at the southern border of the study area.

Review of Previous Inventories and Emission Factors

Only limited information is available concerning soil emissions from tailings piles. Recently, PEDCo [2] has developed an emission factor for this fugitive source by employing the wind erosion equation. No field testing was performed in the PEDCo analysis. Representative characteristics were identified for tailings for use in the wind erosion equation. The piles were described as being composed of sand and loamy sand soils with possible fines for surface cementation. They are charactized by a smooth, unridged surface and no vegetative cover. Wind fetch-over the piles is approximately 2000 feet. Ten percent of the soil loss estimated by the wind erosion equation is assumed to become suspended. The emissions are seasonally related to the climatic factor, which may vary substantially during the year (see Section 4.2). This relationship is illustrated in Table 4-14. Total emissions are calculated by applying the emission factor to the number of acres of tailings piles.

TABLE 4-14. EMISSION FACTORS FOR TAILINGS PILES.

Climatic Factor	Emissions tons/acre/year
30	4.0
40	5.3
50	6.6
60	8.0
70	9.5
80	10.5
90	12.2
100	13.3
120	16.0

Source: Reference [2]

Methodology of the Present Inventory

Based on the historical climatic factor for the study area (.80), the PEDCo emission factor was determined to be 10.5 tons/acre/year. However, data was apparently unavailable to quantify the size and characteristics of tailings piles. No useful data was available from the Arizona State Department of Health, the Pinal County APCD, or the University of Arizona Bureau of Mines. None of these agencies are at present concerned with quantifying the sizes and locations of tailings piles. Attaining information from the individual mines was difficult because of requirements to corporation confidentiality. Due to the relative insignificance of the tailings pile sources, pursuit of the data was abandoned and emissions data from a previous PEDCo inventory were utilized.

The PEDCo estimates were adjusted since PEDCo had inventoried tailings piles in all of Pinal County (1200 acres of piles). This figure was modified by apportioning the total acreage in proportions to the number of employees at the major mines in Pinal County* (Table 4-15). Table 4-16 presents the tailings piles inventory for the Phoenix study area.

*It would have been more direct to base the adjustment on production rates at the mines, but these data were available for only one mine (from the NEDS point source listing).

TABLE 4-15. SIZE OF MAJOR MINES IN PINAL COUNTY.

Company	Location	Number of Employees
ASARCO	Sacaton	360
Hecla	Casa Grande	1150
Magma	San Manuel	4200
	Superior	1150

Source: Reference [25]

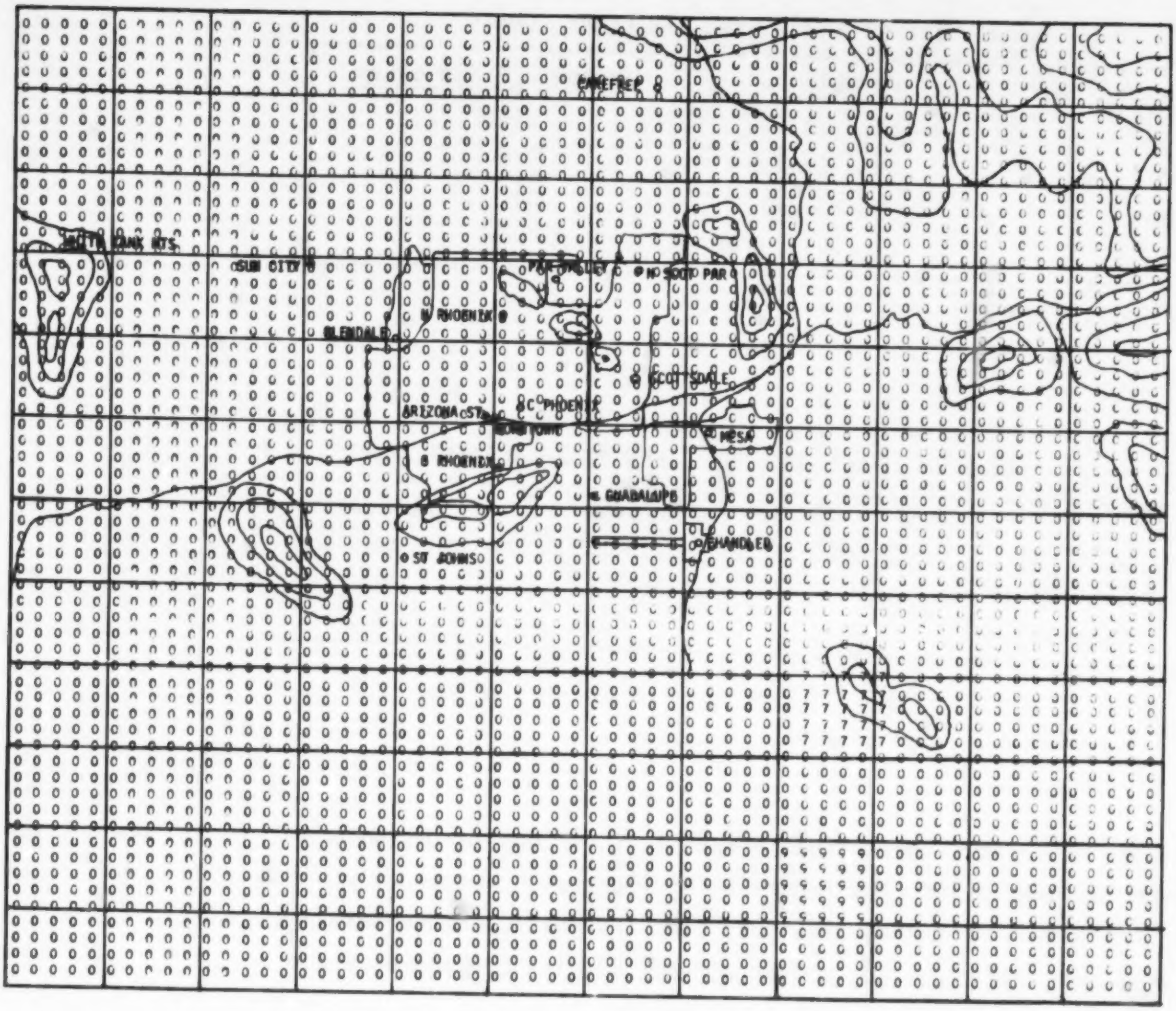
TABLE 4-16. EMISSIONS FROM TAILINGS PILES IN PHOENIX STUDY AREA.

Company	Location	Size of Tailings Piles (Acres)	Emission Factor (tons/acre/yr.)	Emissions (tons/day)
ASARCO	Sacaton	60	10.5	0.3
Hecla	Casa Grande	204	10.5	1.1

Figure 4-17 shows the gridded emissions inventory for windblown dust from tailings piles, and Figure 4-18 illustrates graphically the spatial distribution of the emissions. The insignificance of tailings piles emissions for the study region air quality is heightened by the remote location of this source.

No data were provided by PEDCo as to particle size distributions of the suspended tailings piles emissions. It was assumed that the distribution could be approximated by that of emissions from aggregate loadout operations.

Particle Size (μ)	Weight Percent
<1	30
1-2	46
2-3	16
3-4	6
< 4	4


CAREFREE
SUN CITY
GLENDALE
N PHOENIX
N SCOTT PAR
SCOTTSDALE
ARIZONA ST
C PHOENIX
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 .002
2	.002 to .009
3	.009 to .03
4	.03 to .07
5	.07 to .14
6	.14 to .26
7	.26 to .45
8	.45 to .72
9	.72 to 1.1

Figure 4-17. Emissions Grid Map for Fugitive Dust Arising from Wind Erosion of Tailings Piles, Daily Average, 1975.

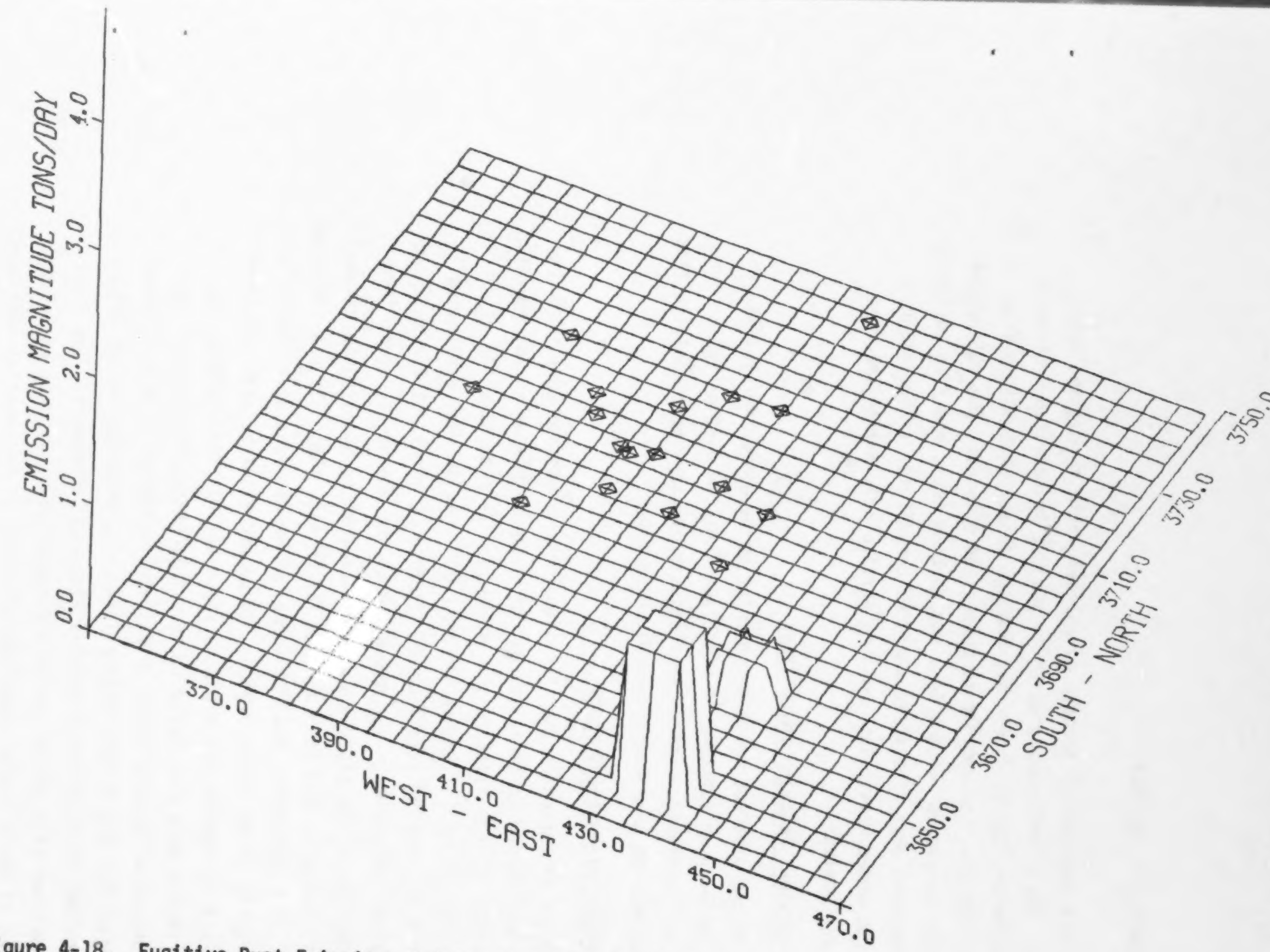


Figure 4-18. Fugitive Dust Emissions Arising from Wind Erosion of Tailings Piles, Daily Average, 1975.

4.6 DISTURBED SOIL SURFACES.

There are substantial amounts of exposed earth throughout the study area. Where the exposed earth is subject to repeated traffic or other disturbance, the surface crust becomes disaggregated into fine particles which are susceptible to suspension by wind. The vulnerable soil surfaces consist of vacant lots and parking lots, and dirt residence yards. Windblown dust from these surfaces constitutes a significant source of suspended particulate matter, particularly during the more windy and dry periods.

Review of Previous Emission Inventories

None of the previous emission inventories developed for the Phoenix area have included an estimate of windblown fugitive dust emissions from distrubed soil surfaces. Established emission factors applicable to this source have not yet been quantitatively determined.

Methodology for Present Inventory

Estimates of suspended dust emissions from distrubed soil surfaces were calculated based on an assignment of value to parameters of the wind erosion model. A suspension factor equivalent to that selected as representative of soil of unpaved roads (.038) was assumed applicable for vacant lots, parking lots, and dirt residence yards. Since an inventory of vacant land acreage was unavailable, the amount of vacant land in each township of the study area was determined by scaling the vacant areas indicated on a 1973 land use map for Phoenix [18]. It was estimated that about 71 square miles (45,200 acres) of vacant land were within the urbanized areas of the study region. These vacant areas were considered to be subject to regular disturbance; those vacant areas outside the urbanized region were considered to be mainly undisturbed desert land.

The amount of exposed earth on private residences with dirt yards was estimated for the Phoenix metropolitan area with the aid of information provided by the City of Phoenix Planning Department. The information consisted of a map of the 1975 Phoenix Census Tracts, including designation of those tracts comprised primarily of residential dwellings having dirt yards. The designations were based on planning personnel familiarity with the Phoenix area. A comparison of the marked census tract map with a map of census tract median family income showed that dirt residence yards were generally located in the economically depressed areas. The marked census tract map was related to the map of the General Land Use Plan for Maricopa County [17] to determine the approximate housing density of the marked tracts. According to the map, the marked tracts consisted of either 0-5 or 5-15 housing units per gross acre. The amount of exposed land was calculated assuming that 27% of the land in the designated areas is used for streets and that 86% of the remaining land is exposed in those tracts averaging 2 1/2 residences per acre and and 34% is left exposed in those tracts averaging 10 residences per acre. These assumptions were based on a special zoning district study conducted by the Maricopa County Planning and Zoning Department [16]. It was also assumed that one fourth of all residence yards in the 0 to 5 dwellings per acre tracts were landscaped with some kind of soil cover, and that one half of the exposed area of the yards is covered or sheltered by buildings or other obstructions. Based on the above assumptions, it was estimated that approximately 3.2 square miles (2020 acres) of exposed residence yards exist within the metropolitan Phoenix area.

The average unsheltered field lengths for vacant and cleared lands was assumed to be 300 by 300 feet. Based on typical dwelling and lot sizes of R1 zoning districts, a distance of 120 feet was selected as the representative unsheltered length of exposed soil strips between dwellings.

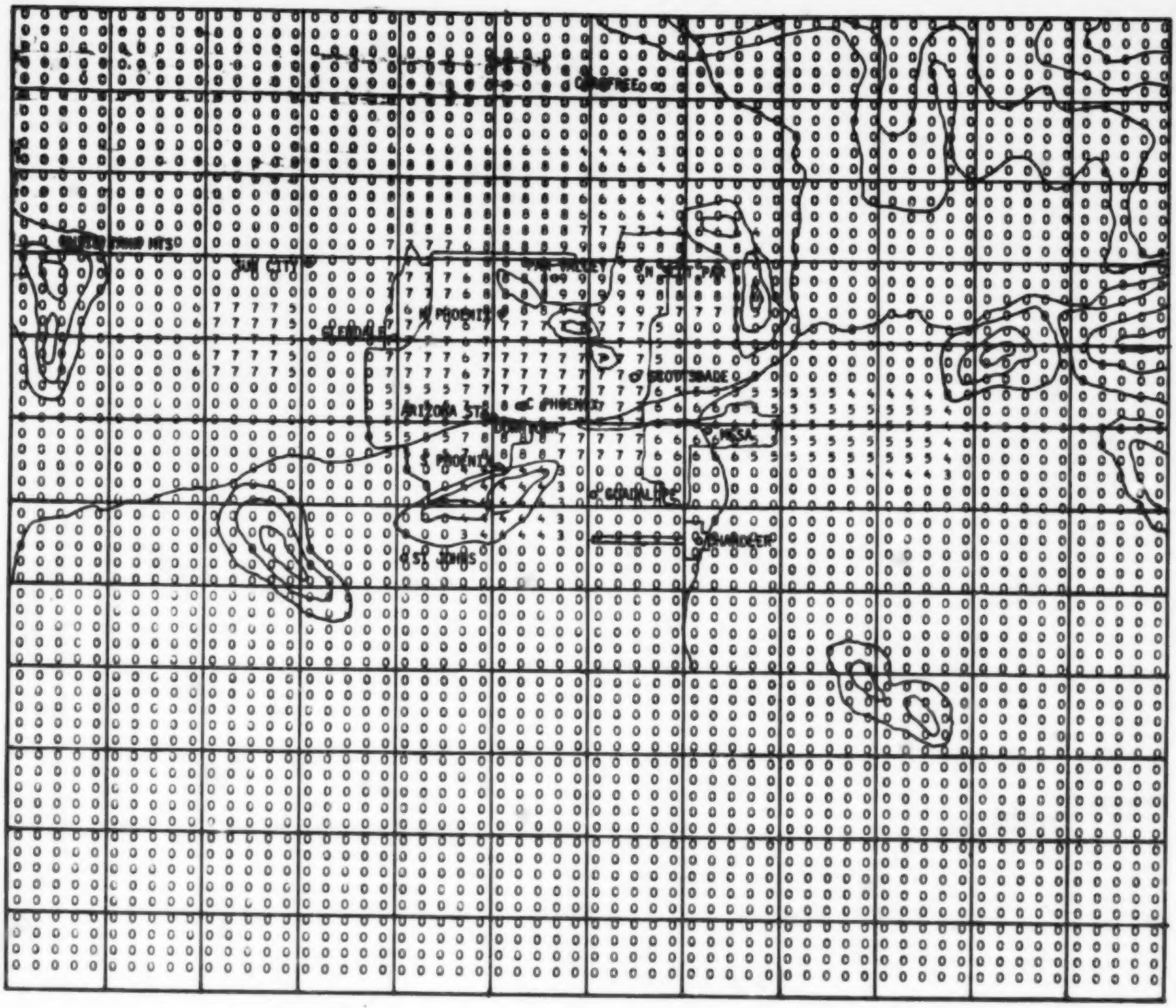
An average value for errodibility of the vacant soils was assumed to be 60 tons/acre/year. This value reflects the average errodibility of non-crusted native soils in Phoenix. An errodibility of 80 tons/acre/year, which reflects the higher extreme of the normal range for native Phoenix soils, was assigned to the highly pulverized soils characteristic of private residence yards.

The climatic factor was calculated to reflect seasonal variations in temperature, wind speed, and precipitation, as described in Section 4.2. Due to lower than normal rainfall and higher than usual wind speeds, dust emissions from vacant lots and residence yards would be significantly greater than usual during 1975. The emissions estimates are shown below. Figure 4-19 illustrates the gridded emissions inventory obtained by calculating emissions for the amount of vacant land or dirt residence yards in each of the cells of the emission grid network. Figure 4-20 illustrates graphically the emissions distribution in the study area.

Quarter	Emissions Tons/Day	Emission Factor, tons/acre/year	
		Vacant lots	Residence yard[illegible]
1	161	1.24	1.45
2	248	1.90	2.22
3	323	2.48	2.90
4	456	3.50	4.10
Year Average	297	2.28	2.67

The particle size distribution of the dust emissions was approximated from parent soil data (see Section 3-6) as follows.

< 2 μ	21%
2-20 μ	54%
20-30 μ	25%


CAREFREE
WHITE TANK MTS
SUN CITY
GLENDALE
N PHOENIX
SCOTTSDALE
ARIZONA ST
C PHOENIX
S PHOENIX
MESA
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .004
2	.004 to .02
3	.02 to .07
4	.07 to .17
5	.17 to .35
6	.35 to .64
7	.64 to 1.1
8	1.1 to 1.7
9	1.7 to 2.7

Figure 4-19. Emissions Grid Map for Fugitive Dust Arising from Wind Erosion of Disturbed Soil Surfaces, First Quarter, 1975.

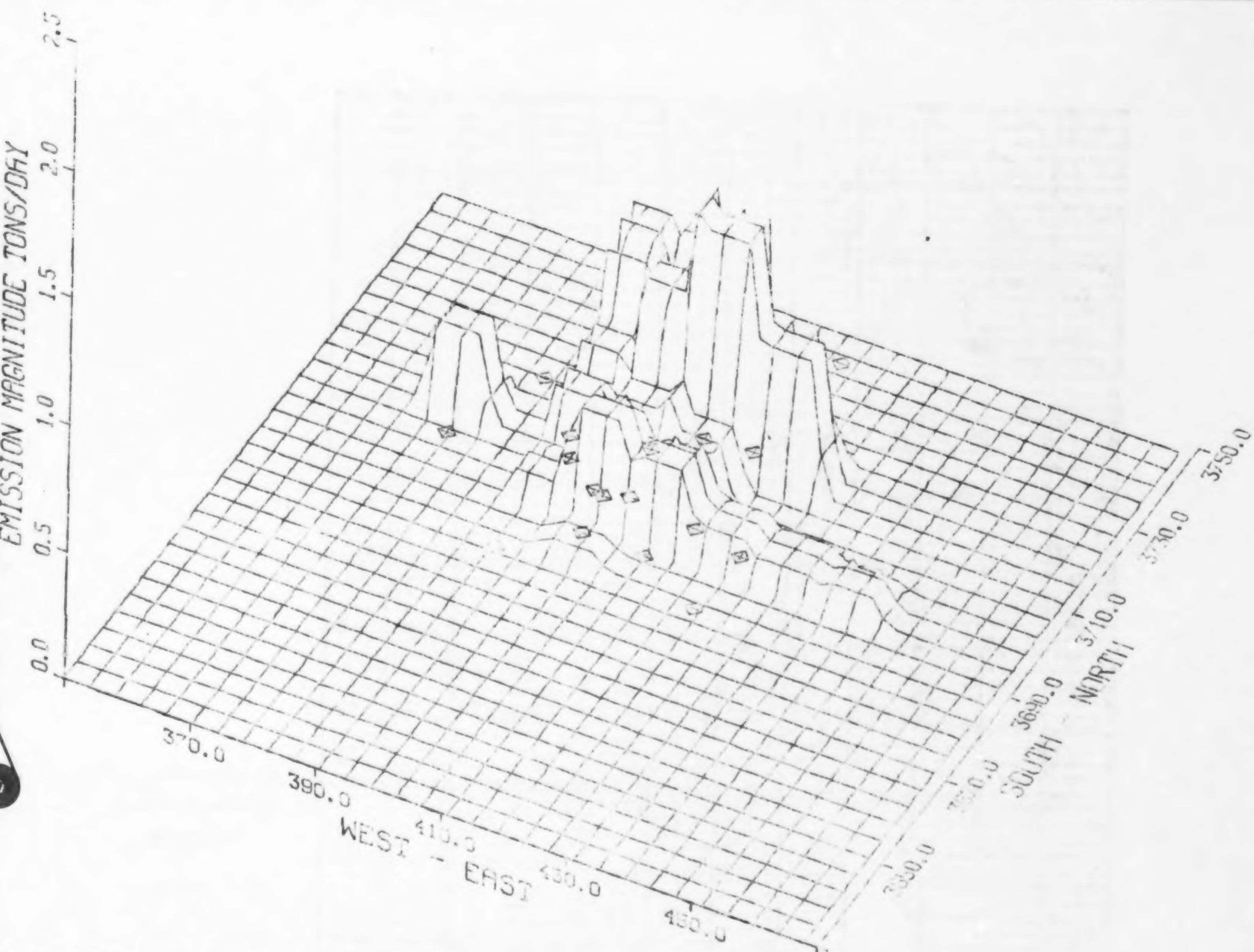


Figure 4-20. Fugitive Dust Emissions Arising from Wind Erosion of Disturbed Soil Surfaces, First Quarter, Daily Average, 1975.

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REFERENCES FOR SECTION 4.0

1. Cowherd, Chatten; Axetell, Kenneth; Midwest Research Institute, "Development of Emission Factors for Fugitive Dust Sources," Prepared for U.S. Environmental Protection Agency, June 1974.

2. Jutze, George; Axetell, Kenneth, PEDCo Environmental Specialists, Inc., "Investigation of Fugitive Dust, Volume I - Sources, Emissions, and Control," Prepared for U.S. Environmental Protection Agency, June 1974.

3. Chepil, W.S., "Dynamics of Wind Erosion: Initiation of Soil Movement," Soil Science, 60: 1945.

4. Gillette, Dale, National Center for Atmospheric Research, "Production of Fine Dust by Wind Erosion of Soil: Effect on Wind and Soil Texture," from Proceedings of a symposium at Richland, Washington, September 1974, on Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants.

5. U.S. Department of Agriculture, Soil Conservation Service, "Soil Survey - Eastern Maricopa and Northern Pinal Counties Area, Arizona," Washington, D.C., 1974.

6. U.S. Department of Agriculture, Soil Conservation Service, "General Soil Map, Maricopa County, Arizona," 1973.

7. Gillette, Dale; Blifford, Irving; National Center for Atmospheric Research, "The Influence of Wind Velocity on the Size Distributions of Aerosols Generated by the Wind Erosion of Soils," Journal of Geophysical Research, September 20, 1974.

8. Shinn, J.H., Lawrence Livermore Laboratory, "Observations of Dust Flux in the Surface Boundary Layer for Steady and Nonsteady Cases," from Proceedings of a Symposium on Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants, September 1974.

9. Midwest Research Institute, "Quantification of Dust Entrainment from Paved Roads," Prepared for Environmental Protection Agency, March 1976.

10. Arizona Crop and Livestock Reporting Service, "Cropland Atlas of Arizona," Phoenix, Arizona, October 1974.

11. Arizona Crop and Livestock Reporting Service, "1974 Arizona Agricultural Statistics," Bulletin S-10, Phoenix, Arizona, March 1975.

12. Cooperative Extension Service, University of Arizona, "Arizona Agri-File, Cotton Water Use," July 1973.

13. Richard, George; Tan, Ron; Avery, Jim, TRW Environmental Engineering Division "An Implementation Plan for Suspended Particulate Matter in the Phoenix Area, Volume I, Air Quality Analysis," Prepared for Environmental Protection Agency, May 1977.

14. Woodruff, N.P.; Siddoway, F.H., Soil and Water Conservation Research Division, U.S. Department of Agriculture, "A Wind Erosion Equation," Kansas Department of Agronomy Contribution No. 897, March 1965.

15. Communication with J.H. Shinn, Lawrence Livermore Laboratory, University of California, May 1976.

16. Maricopa County Planning and Zoning Department, "Data for School Planning," April 1973.

17. Maricopa County Planning Department, "A Report Upon Future General Land Use for Maricopa County, Arizona," February, 1975.

18. Maricopa County Planning Department, "Generalized Existing Land Use, Phoenix, Arizona, 1973."

5.0 PROJECTION OF CONVENTIONAL AND FUGITIVE DUST PARTICULATE/EMISSIONS

One of the major limitations of the previous particulate inventory was that no projections were included. The impact of control strategies were evaluated with respect to current (1970) emissions. If emissions increase over time, then control strategies would not be sufficiently strict to meet the desired levels of air quality; if emissions decreased, then the control strategies would be too stringent. Therefore, to accurately assess the impact of prospective control strategies, baseline emission projections should be developed.

In addition to changes in the magnitude of emission sources, the relative significance of the various particulate sources is expected to change substantially by 1980 and 1985. Fugitive dust emissions produced by human activity (anthropogenic sources) are expected to exert a more pronounced impact on total suspended particulate levels, while particulate emissions from conventional sources and wind erosion of soil are estimated to diminish or remain insignificant in relative importance. The forecast of emission levels from these three emission categories are summarized below.

	EMISSIONS, TONS/DAY		
	conventional sources	anthropogenic sources	windblown dust
1975	34.8	1726	599
1980	42.2	2121	203
1985	50.6	2265	148

This chapter documents the emission projections for each of the emission sources for the years 1980 and 1985. The methodology and emission estimates for these projections are discussed in the following section.

5.1 PROJECTION OF EMISSIONS FOR CONVENTIONAL SOURCES

This section includes a discussion of the methodology employed to forecast particulate emissions levels from conventional sources. These sources consist of motor vehicles, point sources, stationary area sources, and aircraft.

5.1.1 Motor Vehicles

Projections of vehicle miles traveled (VMT) were based upon population projections by the Maricopa County Association of Governments [1]. These population projections are summarized in Table 5-1.

TABLE 5-1. POPULATION PROJECTIONS

YEAR	POPULATION (Millions of Residents)	GROWTH RATIO FROM 1975	VMT (Millions)
1975	1.374	1.000	16.7
1980	1.751	1.274	21.2
1985	2.057	1.497	24.9

Because of the pending controls on automobiles it was necessary to project emission factors also. The catalytic converter results in significant reductions of automobile and light truck particulate emissions. Supplement 5 of AP-42 [4] indicates that only 1975 through 1977 light duty vehicles (LDV's) can be expected to have catalytic converters. After that, it is probable that new control alternatives will cause a return to previous emission levels. Therefore, post-1977 cars are assumed to have the same emissions as pre-1975 cars. Calculations of projected emission factors for 1980 and 1985 cars and light trucks were included in Section 2.0 (Table 2-3 and 2-4) with the baseyear calculations for convenience. Gas and diesel heavy duty vehicle and motorcycle emissions are assumed over the study period.

Projected emissions are based upon the projected VMT and emission factors. The projected emission factors are calculated below:

$$E_o = .731\ (E_{LDV}) + .099\ (E_{LDT}) + .06\ (E_{HDV\ gas}) + .06\ (E_{HDV\ diesel}) + .049\ (E_{mc}).$$

$$E_{1980} = .731\ (.45) + .099\ (.48) + .06\ (1.21) + .06(1.60) + .049\ (.16)$$
$$= .533 \text{ gm/mile.}$$

$$E_{1985} = .731\ (.51) + .099\ (.52) + .06\ (1.21) + .06\ (1.60) + (.049\ (.16)$$
$$= .601 \text{ gm/mile.}$$

The projected emissions from motor vehicles are given in Table 5-2. The emissions are portrayed in the gridded format in Figure 5-1.

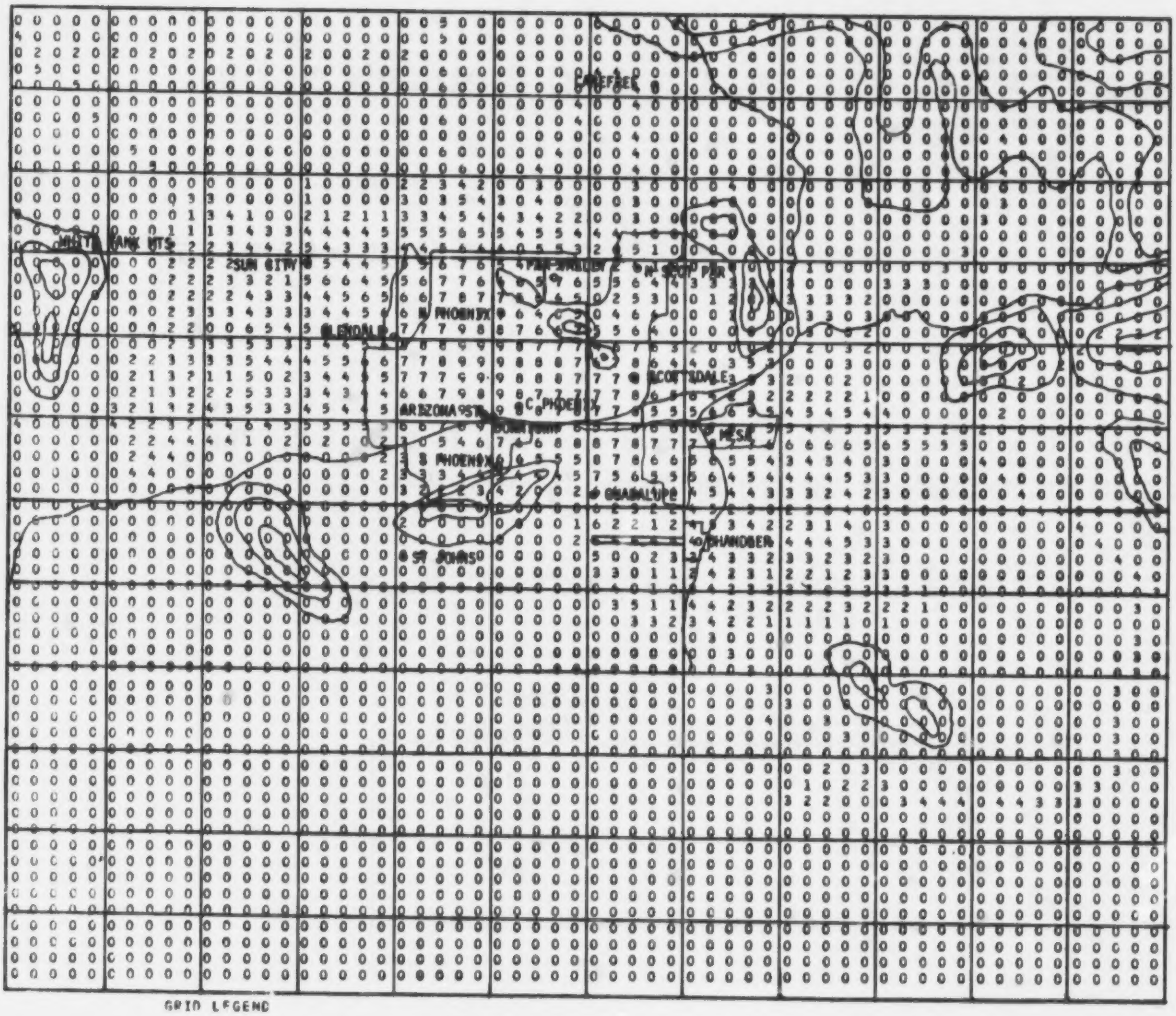
TABLE 5-2. PROJECTED MOTOR VEHICLE PARTICULATE EMISSIONS

YEAR	EMISSIONS (tons/day)
1975	11.0
1980	12.9
1985	16.5

5.1.2 Point Sources

Projections of the 1972 NEDS data were made by using employment data from the Arizona Department of Economic Security [2]. Four categories of employment were used for projecting point sources: (1) mining, quarrying, and rock crushing, (2) manufacturing, (3) agriculture, and (4) utilities. By assuming that emissions are proportional to employment activity, projection factors were developed for each of the first three source categories (utilities are considered separately later in the section).

Historical employment totals and projections are shown in Table 5-3 for the minerals industry and for general manufacturing. These projections were made by the Arizona Department of Economic Security, and


CAREFREE
WHITE TANK MTS
SUN CITY
PAR. VALLEY
N. SCOT PRK
N PHOENIX
GLENDALE
SCOTTSDALE
ARIZONA ST
C. PHOENIX
DOWNTOWN
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID LEGEND

GRID CODE	EMISSIONS TONS/DAY		
0	0.00000	TO	.00000
1	.00000	TO	.00032
2	.00032	TO	.00160
3	.00160	TO	.00505
4	.00505	TO	.01232
5	.01232	TO	.02555
6	.02555	TO	.04734
7	.04734	TO	.08075
8	.08075	TO	.12935
9	.12935	TO	.19715

Figure 5-1. Grid Map for Emissions from Motor Vehicles, Daily Average, 1985.

will be the basis for projecting in the present inventory. These growth factors were applied to the baseyear mineral and manufacturing emissions levels to obtain the forecasted levels for 1975, 1980, and 1985 (the 1975 levels were used for incorporation into the baseyear inventory).

Agricultural employment and crop activity trends are shown in Tables 5-4 and 5-5. Since no employment projections are available for agriculture, projection factors were established by considering historical trends. The data in Table 5-4 indicates a downward trend in employment with a slight recent upswing. A similar trend can be observed in the agricultural crop acreage shown in Table 5-5, except that recent activity levels off, and the cropping activity pattern appears to be about two or three years ahead of the employment data. In view of the diminishing downtrend pattern shown by the data, it appears appropriate to assume a constant activity level for agriculture throughout the study period. Hence, emission levels related to agricultural processing activities were assumed to remain unchanged through 1985.

TABLE 5-3. EMPLOYMENT DATA AND PROJECTIONS

	1972	1973	1974	1975	1980	1985
Mining, Quarying and Rock Crushing						
Employment	400	400	400	400	529	657
Growth From 1972	1.00	1.00	1.00	1.00	1.32	1.64
Manufacturing						
Employment	74,400	82,900	84,200	71,100	95,900	120,700
Growth From 1972	1.00	1.11	1.13	.96	1.29	1.62

TABLE 5-4. AGRICULTURAL EMPLOYMENT IN MARICOPA COUNTY

YEAR	EMPLOYMENT
1970	14,400
1971	13,900
1972	13,525
1973	13,400
1974	13,400
1975	13,600

SOURCE: Arizona Department of Economic Security

TABLE 5-5. AGRICULTURAL CROP AREA IN MARICOPA COUNTY

YEAR	TOTAL CROPPED ACRES
1950	535,000
1955	485,000
1960	524,000
1965	481,000
1970	463,000
1971	443,000
1972	443,000

SOURCE: "Arizona Agricultural" Annual Bulletin of Cooperative Extension Service, Agricultural Experiment Station, University of Arizona.

Beginning late in 1976 or 1977, a new foundary will be producing steel a few miles south of Chandler [3]. Because production has not yet begun, future emission levels for the foundry are not clear. However, with the use of certain design parameters and a few assumptions, it was possible to make an estimate for emissions in 1980 and 1985. The foundary will have two electric arc furnaces each with a 15 ton capacity. By assuming that each furnace is charged at 12 tons and 100 times per week, the operating rate becomes 2400 tons per week or 343 tons per day.

The foundary is to install a 120,000 CFM baghouse for furnace emissions and a baghouse for emissions collected over both the ball wheel and the breaker barrels. It was assumed that the emission factor would be 13 lb/ton [typical value from AP-42] and that the baghouses would control 98% of these emissions. The calculation of emissions is show below:

$$E_{day} = (343\ \frac{\text{Tons Steel}}{\text{Day}})\ (13\ \frac{\text{Lb Particulates}}{\text{Ton Steel}})\ (.02)\ (\frac{\text{1 Ton}}{\text{2000 lb}})$$

$$E_{day} = .0446\ \text{Tons/Day}$$

The foundary is located on Arizona Avenue, South of Chandler, between the cross streets Chandler Heights Road and Riggs Road. By use of a 7-1/2 minute USGS map and a street map of the area it was determined that the UTM coordinates are 421.8 km north and 3676.7 km south to within about .5 km.

Projections of power plant fuel use were available from each of the power companies. The projections are given on an annual basis for each of the plants in the study area. The baseyear seasonal distributions have been assumed to apply to the projections with the exception of the Santan Plant which did not have a complete year of operating data at the time of this study. The power company projection data was applied to the baseyear power plant emission levels to generate seasonal forecasted power plant emissions in 1980 and 1985. These forecasts are shown in Table 5-6. The total projected point source emission levels for the study period are shown below. The emissions are presented in the grid format in Figure 5-2. There are significant changes in the emission levels in future years.

PROJECTED PARTICULATES EMISSIONS FROM POINT SOURCES

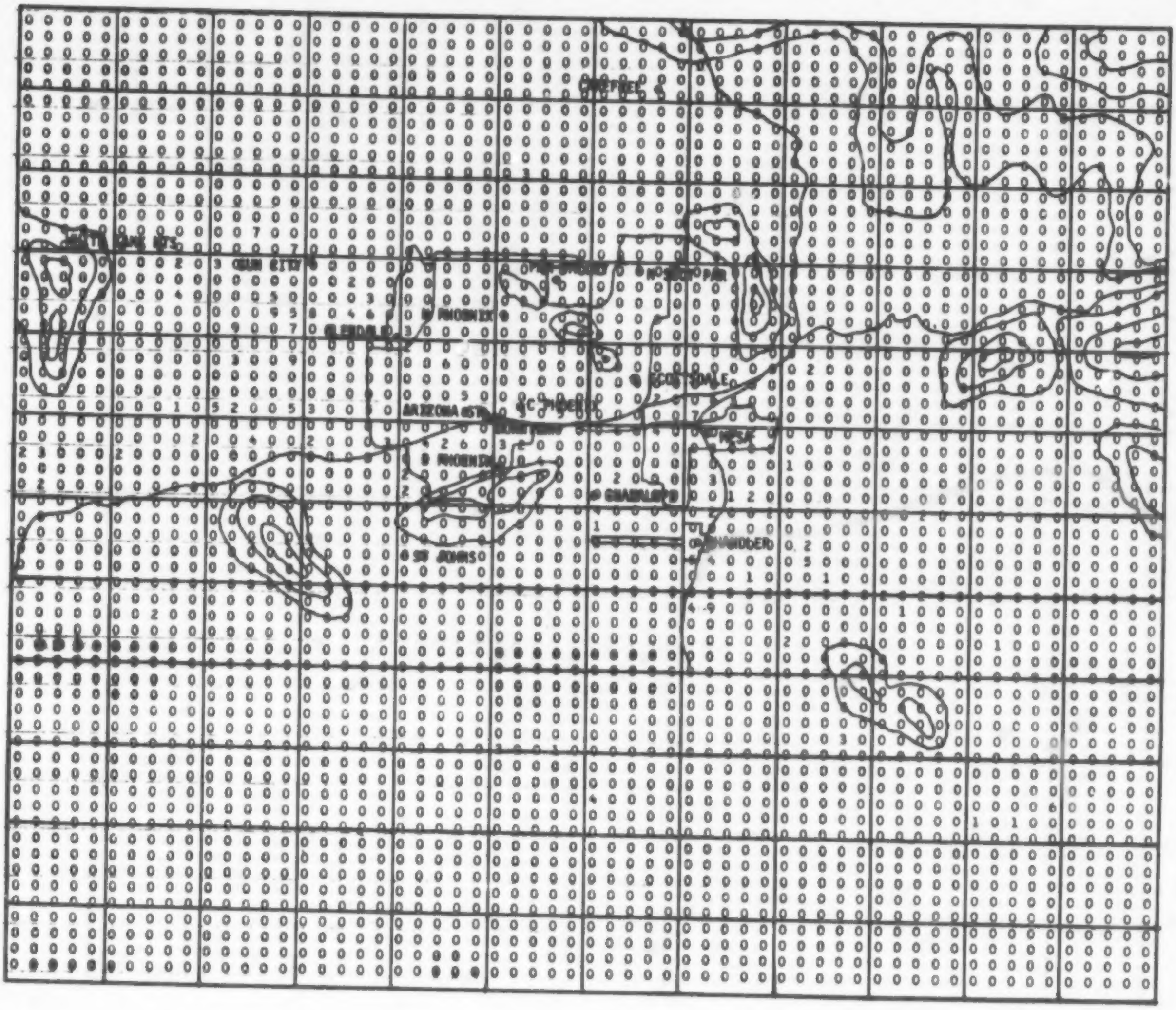
1975 (Baseyear)	21.8 tons/day
1980	27.0
1985	30.8

5.1.3 Stationary Area Sources

Population growth data (see Section 3.1) were used to project space heating emissions to 1980 and 1985. The population distribution was assumed to be unchanged. Projected emission levels are shown in Table 5-7. The emissions are shown in the gridded format in Figure 5-3.

TABLE 5-6. PROJECTED SEASONAL POWER PLANT EMISSIONS
(Tons/Day)

	JFM	AMJ	JAS	OND	ANNUAL AVERAGE
Cross Cut					
1980	0	0	0	0	0
1985	0	0	0	0	0
Agua Fria					
1980	0.854	0.792	1.090	0.740	0.869
1985	0.528	0.490	0.675	0.458	0.538
Kyrene					
1980	0.333	0.274	0.325	0.178	0.277
1985	0.147	0.121	0.144	0.079	0.123
Santan					
1980	0.840	0.778	1.072	0.728	0.854
1985	0.500	0.463	0.638	0.433	0.508
Octillo					
1980	0.679	0.630	0.867	0.589	0.691
1985	0.530	0.491	0.676	0.459	0.539
West Phoenix					
1980	0.494	0.458	0.631	0.429	0.503
1985	0.371	0.343	0.473	0.321	0.377
TOTALS					
1980	3.200	2.932	3.985	2.664	3.194
1985	2.076	1.908	2.606	1.750	2.085

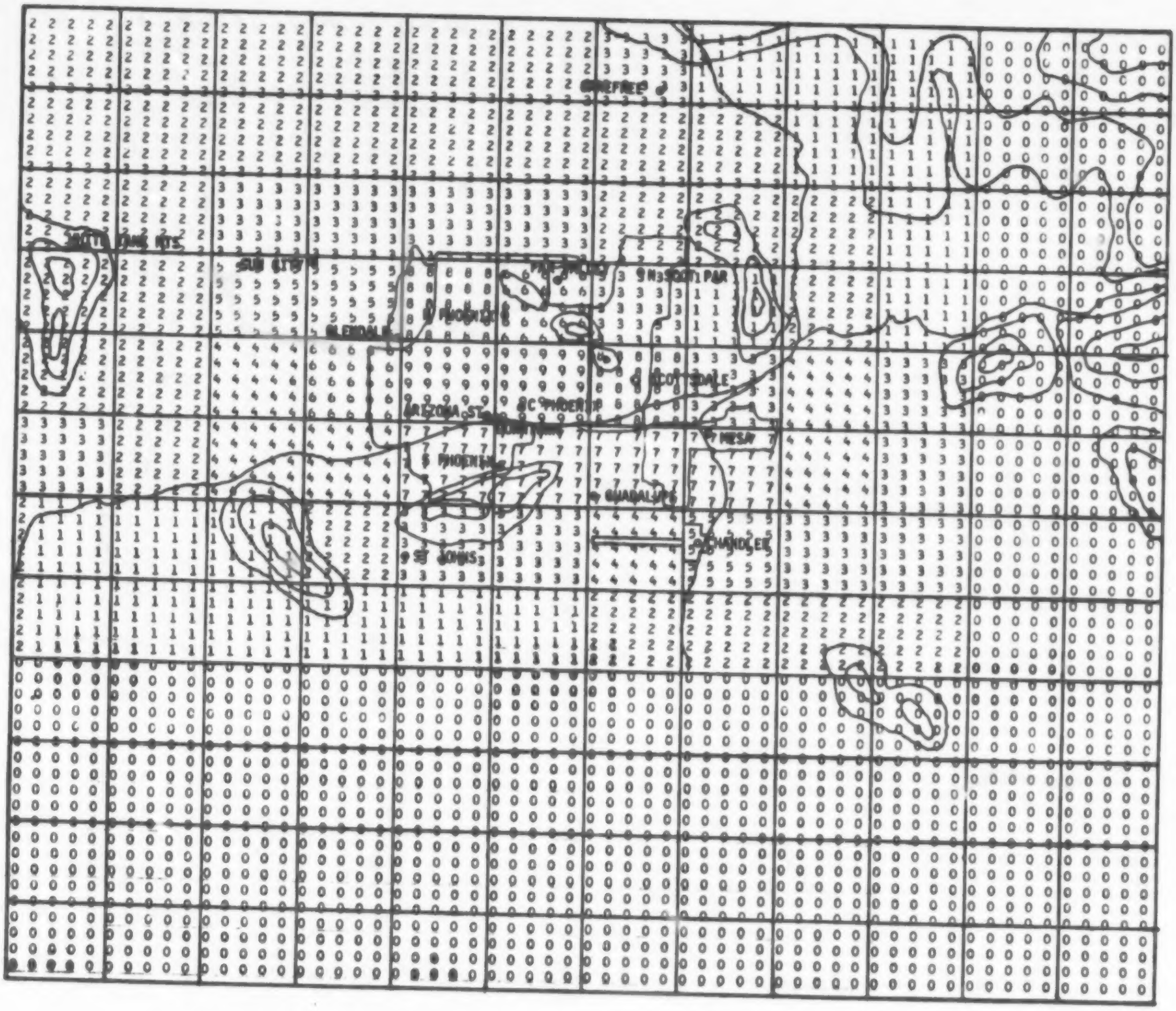

CAREFREE
SUN CITY
GLENDALE
PHOENIX
ARIZONA ST
SCOTTSDALE
MESA
PHOENIX
GUADALUPE
ST JOHNS
CHANDLER

```
          GRID LEGEND

  GRID              EMISSIONS
  CODE              TONS/DAY


   0       0.00000 TO     .00000
   1        .00000 TO     .00444
   2        .00444 TO     .02249
   3        .02249 TO     .07109
   4        .07109 TO     .17355
   5        .17355 TO     .35987
   6        .35987 TO     .66670
   7        .66670 TO    1.13736
   8       1.13736 TO    1.82184
   9       1.82184 TO    2.77677
```

Figure 5-2. Grid Map for Emissions from Point Sources, Daily Average, 1985.


CAREFREE
WHITE TANK MTS.
SUN CITY
GLENDALE
N PHOENIX
SCOTTSDALE
ARIZONA ST
C PHOENIX
S PHOENIX
MESA
GUADALUPE
CHANDLER
ST JOHNS

GRID LEGEND

GRID CODE	EMISSIONS TONS/DAY		
0	0.00000	TO	.00000
1	.00000	TO	.00003
2	.00003	TO	.00013
3	.00013	TO	.00040
4	.00040	TO	.00098
5	.00098	TO	.00203
6	.00203	TO	.00376
7	.00376	TO	.00641
8	.00641	TO	.01027
9	.01027	TO	.01565

Figure 5-3. Grid Map for Emissions from Stationary Area Sources, Daily Average, 1985.

TABLE 5-7. AREA EMISSIONS PROJECTIONS

	1975 (Tons/Year)	1980 (Tons/Year)	1985 (Tons/Year)
Distillate Oil	156.0	198.7	233.4
Natural Gas	350.6	446.7	524.8
TOTAL			
(Tons/Year)	506.6	645.4	758.2
(Tons/Day)	1.39	1.77	2.08

5.1.4 AIRCRAFT

Projections for 1980 and 1985 were developed by utilizing airport growth rates from the Arizona Aviation Systems Plan [5]. These growth rates are shown for each of the five major airports in Table 5-8. Projected activity levels for the two military airports were not available. Activity levels there were assumed to remain constant through 1985. Adjustment of baseyear inventory by the growth rates shown in Table 5-8 yields the forecasted aircraft emission levels (Table 5-9).

TABLE 5-8. ANNUAL OPERATIONS* AND PROJECTIONS FOR FIVE MAJOR CIVILIAN AIRPORTS IN PHOENIX AREA

	Operations (1000)		
	1975	1980	1990
Sky Harbor	328	453	688
Falcon Field	272	383	705
Phoenix Litchfield	214	294	502
Scottsdale	202	346	598
Phoenix Dear Valley	164	196	299

* An operation is either a landing or a takeoff

TABLE 5-9. EMISSION ESTIMATES FOR AIRCRAFT

AIRPORT	Emissions (Tons/Day)		
	1975	1980	1985
Sky Harbor	.190	.262	.330
Falcon Field	.008	.011	.016
Scottsdale	.007	.012	.017
Phoenix Litchfield	.004	.005	.007
Phoenix Dear Valley	.003	.004	.005
Williams AFB	.093	.093	.093
Luke AFB	.054	.054	.054
TOTAL	.359	.440	.520

5.2 ANTHROPOGENIC SOURCES

This section discusses the methodology employed in projecting emissions from vehicles on unpaved roads, agricultural tilling, aggregate storage piles, cattle feedlots, off-road motor vehicles and the entrainment of fugitive dust by motor vehicles on paved roads.

5.2.1 Motor Vehicles on Unpaved Roads

Several studies were examined in an attempt to predict future trends of both miles of unpaved roads and traffic volumes on unpaved roads [6,7,8,9,10]. These documents, however, proved to be of no assistance, as their predictions were based on road-functional classifications (i.e. collector and local streets, interstate highways) and not on road surface type. An attempt was then made to extrapolate past trends of unpaved road mileages. However, no discernable trends were found to exist.

Ultimately, knowledgeable officials at both the county and city levels were contacted and their expertise solicited. The following sections detailed the information received:

(1) The Maricopa County Highway Department - the County has historically paved approximately 50 miles of unpaved roadways per year. Three criteria govern the selection of roads to be paved - (1) ADT, (2) development of subdivisions and (3) accident reports from the Sheriff's Department. Thus, no systematic pattern exists. There is a County ordinance requiring the paving of all streets in new County subdivisions. This ordinance, however, is not retroactive. No new unpaved roads are expected to be created in the future due to this ordinance.

(2) Phoenix - the city, in 1960, embarked upon a program to upgrade all substandard streets,* with a goal of 30 miles per year in mind. The actual trend has been closer to 18 miles per year. Most of the unpaved roads are in existing subdivisions, with a very small portion in commercial and industrial areas. No new unpaved roads are expected to come into existance, as there is a city ordinance requiring all streets in new subdivisions to be paved.

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*A substandard street is one that is not paved and does not have gutters and curbs. Thus both unpaved streets as well as paved ones without gutters and curbs are classified as substandard. In Phoenix, only collector and local streets are substandard.

(3) Mesa - there are presently only 17 miles of unpaved streets in Mesa. Of these, 10 miles are in subdivisions and the remaining 7 miles are arterials. The city is paving the arterials through capital improvement programs and expects to be through by 1985. The residential unpaved streets are improved only when the local residents form Improvement Districts. All new subdivisions are required to have paved streets.

(4) Scottsdale, Chandler, Glendale, Temne, Paradise Valley - the situation is similar in all these cities; thus they will be discussed as a unit. Almost all unpaved roads are located in existing subdivisions, with a very small percentage as arterials. Residential unpaved roads are paved only through the formation of Improvement Districts. There is no schedule to pave the arterial streets. All new subdivisions are required to have paved streets.

To summarize the situation in Maricopa County, it appears that no new (i.e. not presently existing) unpaved roads will be created in the future. In all cities except for Phoenix, there will still be unpaved roads, of which almost all are in existing subdivisions. These are not expected to be paved very rapidly, as the number of miles paved through the formation of Improvement Districts has been extremely low historically (on the order of 2-4 miles in the last 10 year period). As for Phoenix, the majority of existing unpaved streets will probably be paved by 1985.

One fact complicates the projection of mileages of unpaved roads on a spatial basis. Phoenix and its neighboring cities have historically experienced a rapid increase in population and can be expected to continue experiencing this trend. County land is annexed and the cities assume responsibility for the maintenance of all roads in the annexed land. What plans the cities may have to pave unpaved roads in these annexed areas is unknown. As TRW's data on the spatial distribution of unpaved roads is on a maintenance area basis, the removal of mileages and the uncertainty as to the disposition of unpaved roads in the annexed lands requires several assumptions to be made.

Projections for Maricopa County

In the city of Phoenix, all existing unpaved roads (121 miles) will be paved at the rate of 11 miles/year. This figure is derived from the fact that the rate of upgrading substandard streets in Phoenix is 18 miles/year and 121 of the remaining 200 miles of substandard streets are unpaved [(121/200) x (18) = 10.89 or 11]. For Mesa, 25% of the 10 miles of unpaved residential roads are assumed to be paved by 1980 and 50% by 1985. The remaining 7 miles of unpaved arterial roads are expected to be paved by 1985. For 1980, it is assumed that 3 of the 6 miles will be paved. In the remaining cities (Scottsdale, Chandler, Tempe, Glendale and Paradise Valley), all existing unpaved streets will be assumed to be paved (through the formation of Improvement Districts) at the following rate - 25% of the total unpaved mileage to be paved by 1980 and 50% of the total by 1985. (This strategy assumes that all unpaved roads in the remaining cities are in residential areas. This is a plausible assumption, as the majority of the unpaved roads are in residential areas).

To estimate the future distribution of unpaved road mileages, the following procedure was employed:

(1) Figure 5-4 illustrates the urbanized areas in Maricopa County in 1985. By overlaying a map showing the present boundaries of urbanization, the locations of future growth were determined.

(2) A second overlay depicting the Highway Department maintenance areas was then utilized to determine the expansion of urbanization into each maintenance area.

(3) A third overlay with the network of all road types* was also placed over Figure 5-4 and the first two overlays to obtain:

  a. The mileages of all road types in a maintenance area.
  b. The mileages of all road types in the urbanized portion of a maintenance area.

(4) To determine the mileage of unpaved roads in the urbanized portion of a maintenance area, the following procedures was implemented:

  a. Calculate the percentage:

$$C_p = \frac{\text{Miles of all road types in the urbanized area of a maintenance area}}{\text{Miles of all road types in the maintenance area}} \times 100$$

  b. Multiply C_p times the miles of unpaved roads in the maintenance area (given in Table 4-11) to obtain the miles of unpaved roads in the urbanized portion of the maintenance area.

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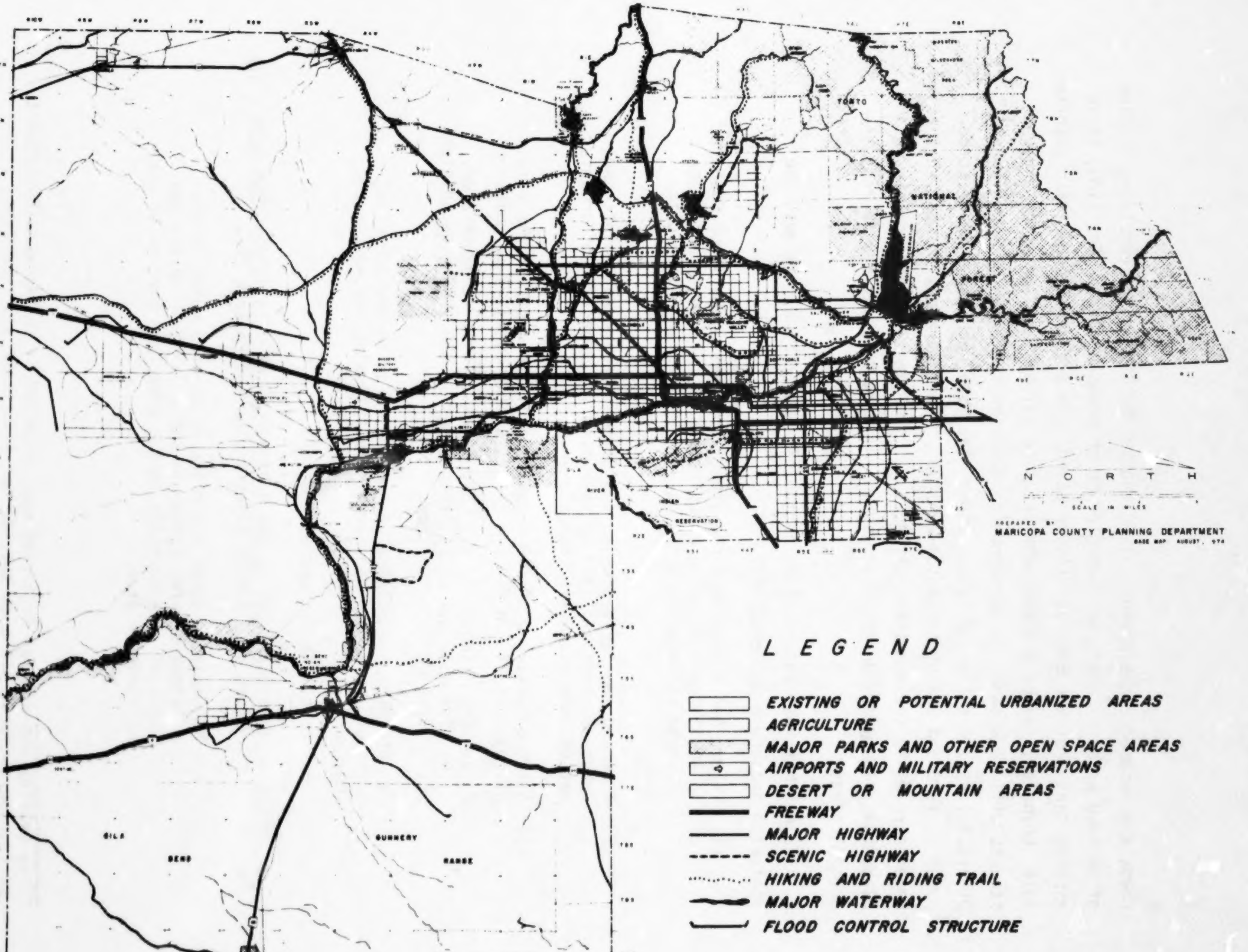
*This overlay was adopted from road maps provided by the Arizona Department of Transportation. Although they do not illustrate all road types in the County, these maps were the best available for spatial distribution.


TONTO
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GILA RIVER
INDIAN
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SCALE IN MILES
PREPARED BY
MARICOPA COUNTY PLANNING DEPARTMENT
BASE MAP AUGUST, 197
L E G E N D
EXISTING OR POTENTIAL URBANIZED AREAS
AGRICULTURE
MAJOR PARKS AND OTHER OPEN SPACE AREAS
AIRPORTS AND MILITARY RESERVATIONS
DESERT OR MOUNTAIN AREAS
FREEWAY
MAJOR HIGHWAY
SCENIC HIGHWAY
HIKING AND RIDING TRAIL
MAJOR WATERWAY
FLOOD CONTROL STRUCTURE

Figure 5-4. Future General Land Use, Maricopa County, Arizona [15].

(5) As an example of Steps (1) through (4), consider maintenance area I-F. From Steps (1), (2) and (3), it was determined that 38% of all the roads in I-F would fall into urbanized portions by 1985. From Table 3-4, plus the assumption 40% of all county maintained unpaved roads are gravel, the total miles of unpaved roads in I-F is 137 (93 dirt miles and 44 gravel miles). Thus (.38) x (93 miles) = 35 miles of dirt and (.38) x (44) = 17 miles of gravel roads are allocated to the urbanized section of Area I-F in 1985.

(6) This methodology is performed for each maintenance area subject to urbanization and the results can be seen in Table 5-10.

(7) All mileages of dirt and gravel roads determined in Steps (1) - (6) are assumed to be paved by 1985.

(8) Since it is assumed that the Highway Department paves 50 miles of road/year, it is expected that 500 miles of paving will occur from 1975 to 1985. Steps (1) - (6) account for only 372 of these miles (see Table 5-10). The assumption is made that the remaining 128 miles of roadway to be paved in this period will be done according to transportation needs indirectly associated with urbanization. Therefore, the remaining 128 miles is distributed proportionally among the maintenance areas subject to urbanization. The proportionality constant is determined by dividing the total miles of road to be paved in each maintenance area by the total number of miles of road to be paved in all maintenance areas. For instance, according to Table 5-10, 35 miles of dirt and 17 miles of gravel roads in area I-F are due to be paved by 1985. The proportionality constants are:

$$\text{Dirt} = \frac{35}{372} \times 100 = 9\%$$

$$\text{Gravel} = \frac{17}{327} \times 100 = 4\%$$

Thus, (.09) x (128) = 12 additional miles of dirt roads and (0.4) x (128) = 5 additional miles of gravel roads will be paved by 1985. The total mileages of unpaved roads to be paved in I-F are:

Dirt = 35 (due to urbanization) + 12 (due to indirect needs) = 47 miles

Gravel = 17 (due to urbanization) + 5 (due to indirect needs) = 22 miles

(9) Fifty percent of the paving in all maintenance areas by 1985 is assumed to occur by 1980.

(10) In addition to the change in miles of unpaved roads, the ADT in all maintenance areas and cities is assumed to increase at the same rate which the population is expected to increase from 1975 to 1980 to 1985 [1].

1975 → 1980 : 27.4%
1975 → 1985 : 49.7%

TABLE 5-10. PROJECTION OF UNPAVED ROAD MILEAGES IN MARICOPA COUNTY

Maintenance Areas Subject to Urbanization in Study Area	Percent of Total Road Mileage of the Maintenance Area in the Urbanized Portion of the Maintenance Area	Miles of Unpaved Roads in 1975 in Maintenance Area		Miles of Unpaved Roads to be Paved Due to Urbanization in each Maintenance Area in 1985		Paving Proportionality Constant, C_p [a]		Total Miles of Paved Road in Each Maintenance Area in 1985		Total Miles of Unpaved Roads in Each Maintenance Area			
										1980		1985	
		Dirt	Gravel	Dirt	Gravel	Dirt	Gravel	Dirt	Gravel	Dirt	Gravel	Dirt	Gravel
I-B	2	147	44	3	1	1	0.5	4	2	145	43	143	42
I-C	3	72	30	22	9	6	2	30	12	52	24	42	18
I-D	15	71	32	11	5	3	1	15	6	64	29	56	26
I-E	3	94	45	3	1	1	0.5	4	2	92	44	90	43
I-F	38	93	44	35	17	9	4	47	22	70	33	46	22
II-A	33	197	77	65	28	17	6	87	33	154	61	110	44
II-B	12	125	54	15	7	4	2	20	10	115	49	105	44
II-E	3	103	51	3	2	1	1	4	3	101	50	99	48
III-A	12	101	38	12	5	3	1	16	6	93	35	85	32
III-B	3	109	55	3	2	1	1	4	3	107	54	105	52
III-C	2	68	28	1	1	0.5	0.5	2	2	67	28	66	26
III-D	6	72	31	4	2	1	1	5	3	70	30	67	28
III-I	99	61	23	60	23	16	5	80	31	21	8	0	0
IV-B	30	52	17	16	5	4	1	21	6	42	14	31	11
IV-C	2	72	30	1	1	0.5	0.5	2	2	71	29	70	28
IV-D	2	142	77	3	2	1	1	4	3	140	76	138	74
IV-E	5	92	44	5	2	1	1	6	3	89	43	86	41
TOTAL		1671	720	262	110	70	30	351	149	1498	648	1339	579

[a] See Section 5.2.1 for the explanation of c_p.

5-18
50%

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(11) Emission projections are also affected by rainfall predictions (See Section 3.1). Typical meteorology is assumed to prevail in 1980 and 1985 as shown below:

Quarter of year	Number of days .01 inch or more of rain	Fraction of days .01 inch or more of rain
1	11	.12
2	4	.04
3	12	.13
4	9	.09
year	36	.09

Projections for Pinal County

As no data was available for Pinal County, it is assumed that no change in the mileage of unpaved roads will occur. The ADT is expected to increase at the following rate:

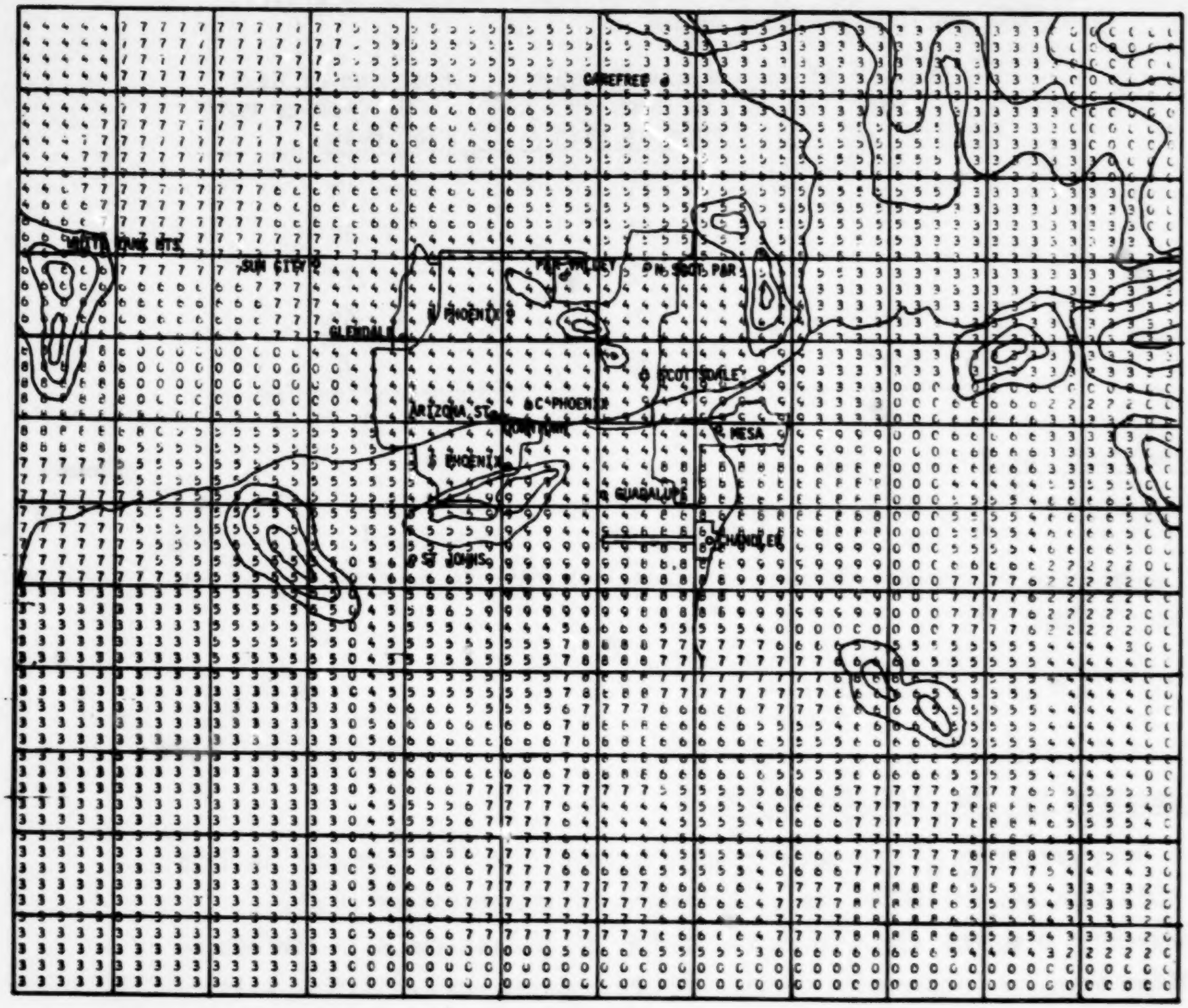
1975 → 1980 : 27.4%
1975 → 1985 : 49.7%

Projections for the Total Study Area

Dust emissions from unpaved roads increase from 1281 tons/day in 1975 to 1553 tons/day in 1985. The distribution of the emissions change as improvement programs will reduce the number of unpaved roads in the metropolitan area. An increasing portion of the unpaved road emissions will be generated at the perimeter of the urban areas and outside the boundaries of the city of Phoenix. Figure 5-5 presents the grid map of emissions arising from unpaved roads as forecast for 1985. Figure 5-6 illustrates graphically the distribution of unpaved road dust emissions.

5.2.2 Agricultural Tilling

Knowledgeable personnel at the College of Agriculture, University of Arizona [13] were consulted as to projected growths or declines in cropland average. These conversations revealed that total crop acreages in Maricopa and Pinal Counties have not changed substantially in the last 26 years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C PHOENIX
DOWNTOWN
MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to 005
2	0 to .02
3	.02 to .07
4	.07 to .18
5	.18 to .37
6	.37 to .68
7	.68 to 1.2
8	1.2 to 1.9
9	1.9 to 2.8

Figure 5-5. Grid Map for Dust Emissions from Motor Vehicles on Unpaved Roads, 1985.

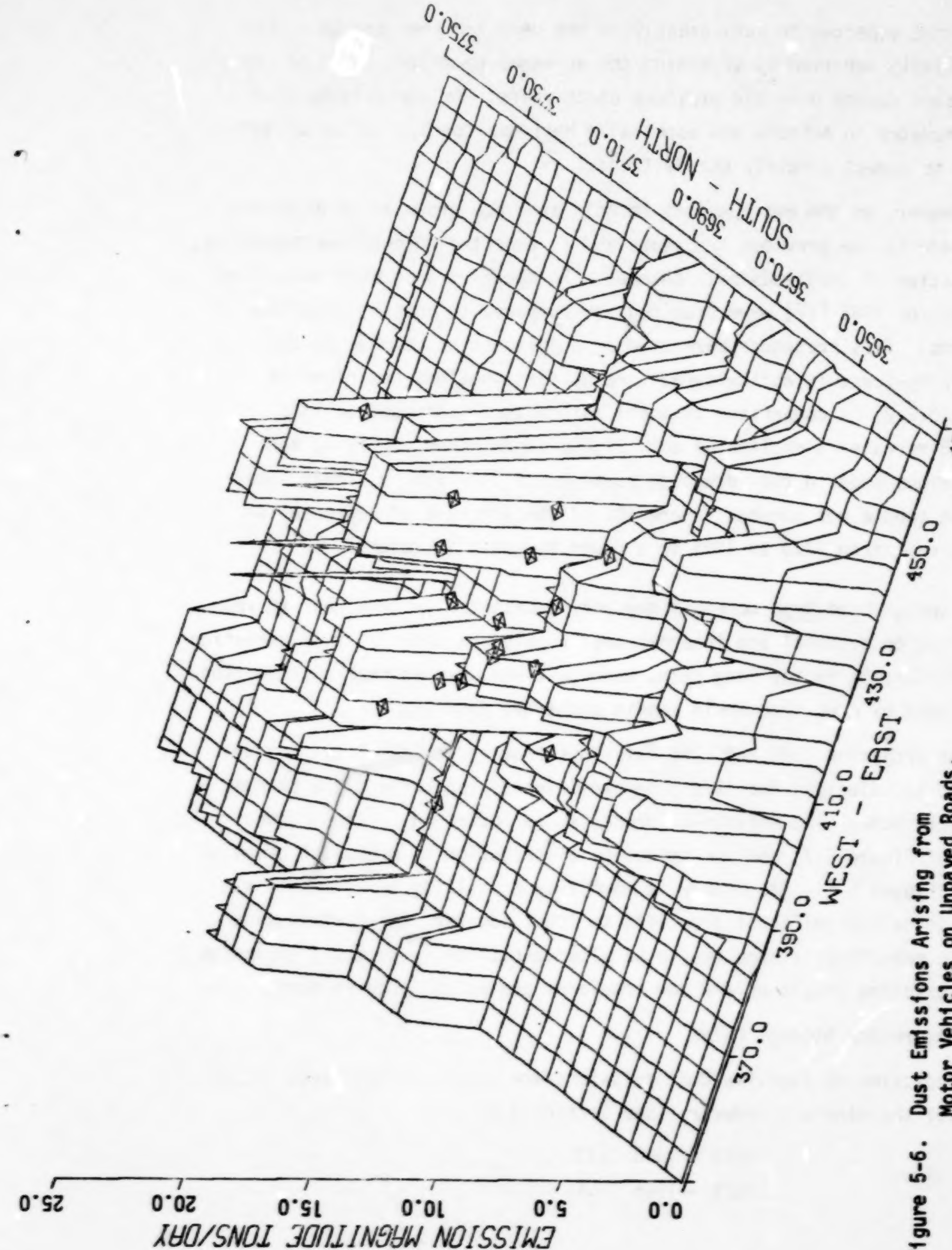


Figure 5-6. Dust Emissions Arising from Motor Vehicles on Unpaved Roads, Daily Average, 1985.

and are not expected to vary greatly in the next ten year period. This was partially verified by examining the acreages committed to major crops in Maricopa County over the previous eight years. As agriculture is a major industry in Arizona and especially Maricopa County, it is not surprising to expect a fairly steady trend.

However, as the metropolitan Phoenix area has grown at an extremely rapid pace in the previous ten years and is expected to continue expanding, the location of croplands will change. To document this phenomena, land use maps for 1985 [17] were examined and compared to present locations of croplands. This procedure permitted an adjustment to be made to the township-by-township agricultural acreage distributions described in Section 3.2.2. A comparison of total agricultural acreages in 1985 and 1975 revealed a decline of only 31,000 acres, thus verifying the observations made in the foregoing paragraph. For 1980, a linear interpolation scheme was adopted, where 50% of the increase or decrease in crop acreage from 1975 to 1985 in a given township is assumed.

Although crop type acreages may vary substantially from year to year (depending on national and international supply and demand), this variation is unpredictable in the long term, hence, it was assumed that distribution of cropland by crop type would remain unchanged from 1975.

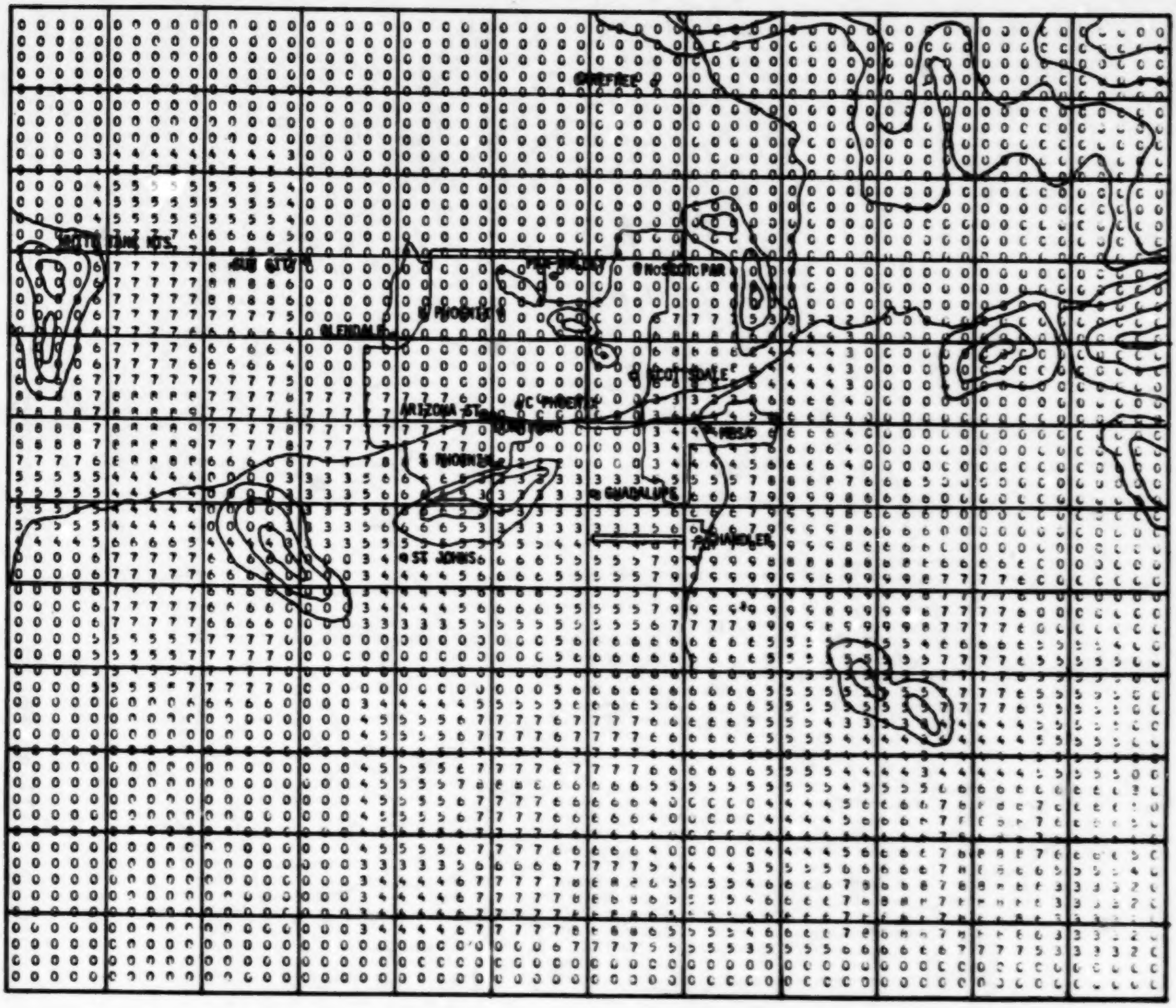
The projected 1980 and 1985 emissions from agricultural tilling are obtained by adjusting the 1975 baseyear inventory to reflect the changes discussed above. The emissions forecasts are portrayed in the gridded format of Figure 5-7, and the emissions distribution is presented graphically in Figure 5-8. The change in magnitude of tilling emissions is expected to be insignificant from 1975 to 1985, however, the distribution of these emissions is expected to be altered noticeably as urban expansion claims existing croplands and new croplands are established in turn.

5.2.3 Aggregate Storage Piles

Projection of fugitive dust emissions are based on employment projections for the minerals industry (see Section 3.0):

1975 → 1980 +32%

1975 → 1985 +64%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MESA
S PHOENIX
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY		
0	0.00000	TO	.00000
1	.00000	TO	.00006
2	.00008	TO	.00042
3	.00042	TO	.00132
4	.00132	TO	.00322
5	.00322	TO	.00668
6	.00668	TO	.01237
7	.01237	TO	.02110
8	.02110	TO	.03380
9	.03380	TO	.05151

Figure 5-7. Grid Map for Emissions Arising from Agricultural Tilling, 1985.

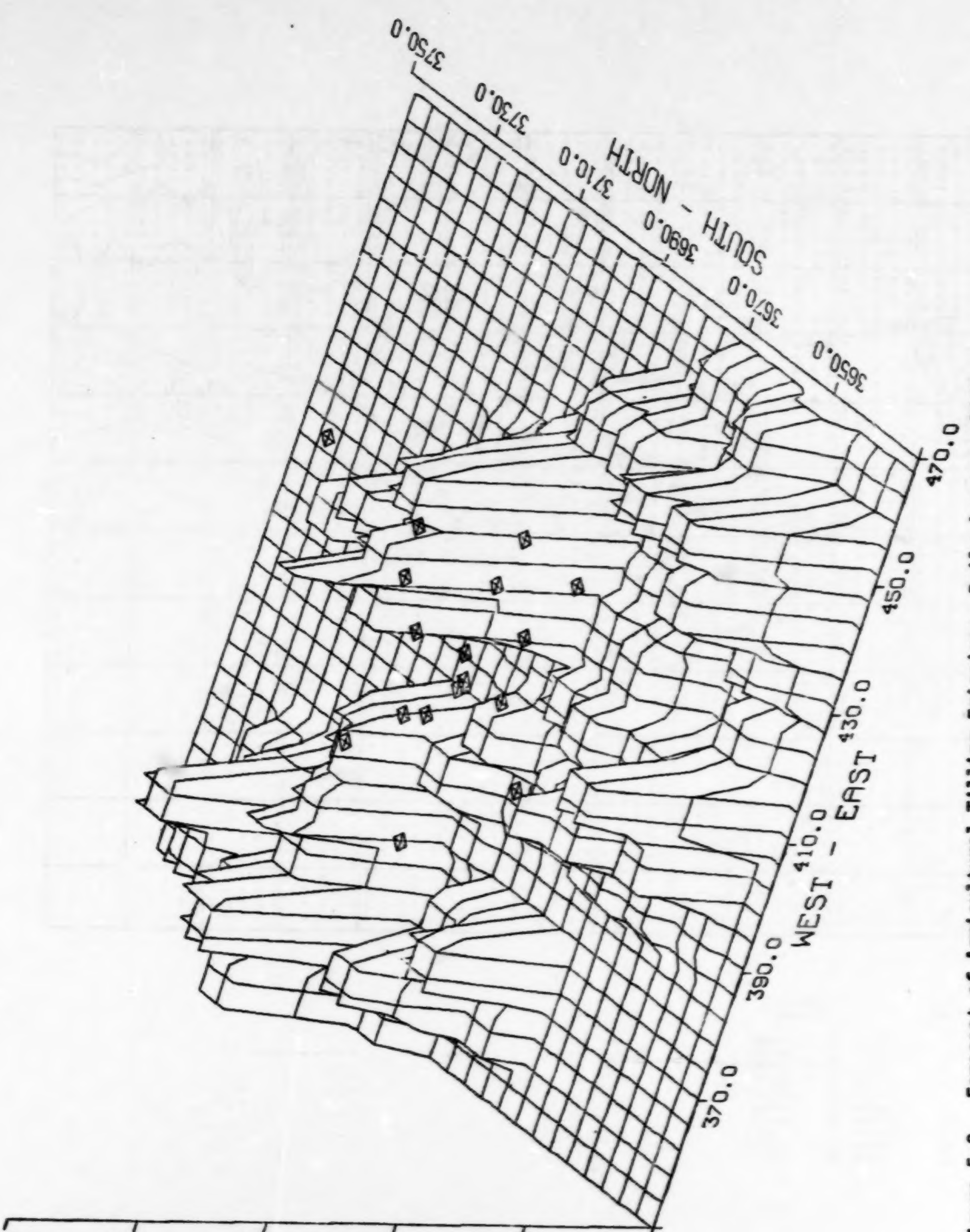


Figure 5-8. Forecast of Agricultural Tilling Emissions, Daily Average, 1985.

To obtain the projected emissions levels, the baseyear inventory of aggregate pile emissions is adjusted to reflect the employment forecasts. Table 5-11 summarizes the emissions forecasts. The location and number of sources are assumed to remain unchanged.

TABLE 5-11. PROJECTED FUGITIVE DUST EMISSIONS FROM AGGREGATE STORAGE PILES

Year	Emissions, tons/day
1980	.073
1985	.091

5.2.4 Cattle Feedlots

The Maricopa County Agricultural Agent [14] was consulted as to future trends in cattle feedlot sizes. The following facts are pertinent:

- As is the case with most agricultural products, cattle feeding depends greatly upon the weather conditions and the nationwide economy. Thus, trends are extremely difficult to predict.
- The number of cattle on feed in the study area (see Table 3-17) during 1975 represents a low year; only 40%-60% of the capacity of the feedlots were utilized. The corresponding figures for 1976 should be up to 80% capacity.
- The best guess estimate for the 1975-1985 period given by the Agricultural Agent is that the number of cattle on feed should be at least 50% greater than the number on feed in 1975.

Thus, the methodology employed to predict future emissions consists of adjusting the baseyear inventory to reflect an increase in the number of cattle-on-feed by 50 % for both 1980 and 1985. Accordingly, emissions are increased by 50% over the baseyear levels (see Table 5-12).

5.2.5 Off-Road Motor Vehicles

As off-road vehicle use is a recreational activity, the projections will be proportional to the growth rate in population as forecasted by

TABLE 5-12. PROJECTED FUGITIVE DUST EMISSIONS FROM CATTLE FEEDLOTS IN THE STUDY AREA

County	1980 and 1985 Emissions tons/day
Maricopa	3.2
Pinal	5.1
Total, study area	8.3

the Maricopa Association of Governments [1].

The location of off-road vehicle activity is assumed to remain unchanged with the exception of the area of Sun City, where it is assumed off-road activity will be eliminated due to planned urban expansion and local ordinances. The projected emissions are summarized in Table 5-13.

TABLE 5-13. PROJECTED EMISSIONS FROM OFF-ROAD MOTOR VEHICLES

	Emissions (tons/day)	
	1980	1985
Motorcycles	68.0	80.0
Motor Vehicles	23.0	27.0
Total	91.0	107.0

5.2.6 Construction Activities

Based on the general future land use plan for Maricopa County [15], urbanization development is expected to occur at the rate of 18.7 square miles per year from 1973 to 1990. Figure 5-4 shows the forecasted area which will be developed by 1990. The developed portion represents 640 square miles. By contrast, the existing urbanized area in 1973 comprised some 323 square miles.

Estimates of land areas involved in construction for 1980 and 1985 were assumed to be consistent with the forecasts of the County General Plan. 18.7 square miles of new urbanization development occurs annually. Roadway construction improvements also contribute a significant amount of additional soil disturbance, and consequently, dust emissions. These improvements are expected to occur at the rates shown in Table 5-14. Expected dust emissions arising from these activities are also shown in Table 5-14. These dust emissions may be located within the computerized emissions grid as area sources spread throughout the region of agency jurisdiction, except for those activities of the State Highway Department, which were located according to the forecasted State Highway Future General Plan[16].

TABLE 5-14. ANNUAL STREET IMPROVEMENTS SCHEDULED FOR MARICOPA COUNTY OVER NEXT TEN YEAR PERIOD.

Agency	Improvements miles/year	Acres of Soil Disturbed	Emissions Average tons/day
County	20[a]	133	1.8
Phoenix	40[b]	274	3.6
Glendale	1[c]	6.7	.1
Paradise Valley	1[c]	6.7	.1
Scottsdale	1.2[c]	8.0	.1
Chandler	.4[c]	2.7	-
Mesa	1.7[c]	11.4	.2
Tempe	.3[c]	2.0	-
State Highway Dept.	37	360	7.1
		804.5	13.0

a. Representative value based on previous years[17].

b. This value is based on targeted 20 mile/year rate of the Improvement District for upgrading local streets, and a 20 mile/year program of the Traffic Department for improvment of major streets in 1980[18,19].

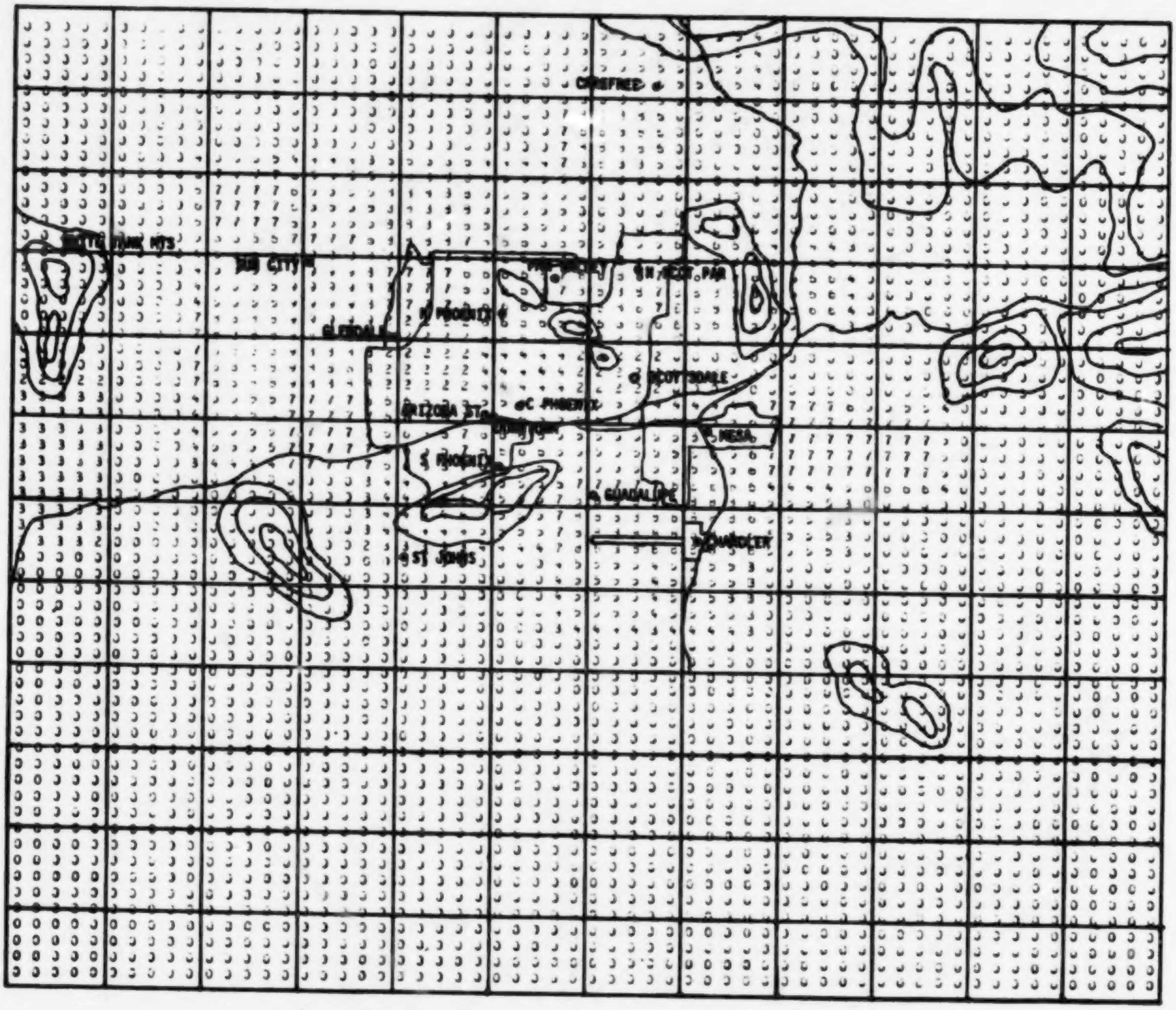
c. Based on conservative assumption that improvements by cities will at least account for upgrading all unpaved roads by 1985.

Development of 18.7 square miles of land in 1980 and 1985 (assuming an active construction duration of 6 months) will result in an estimated dust loading of 86,300 tons/year, or an average of 246 tons of dust emissions per day. The location of the development will proceed outward from the center of the cities in the Phoenix area. A geometric mapping procedure was used to estimate the location of the construction activity in 1980 and 1985. Isolines reflecting the constant rate of expanding development were constructed for the years 1980 and 1985 by interpolating between the boundaries of the existing developed area and that developed area forecasted by the 1990 Future General Land Use Plan. The differential development in the years 1980 and 1985 was assumed to occur within a growth belt representing the expanded urbanization over the past five year period. The forecasted dust emissions loadings were apportioned according to the relative area of the growth belt in each of the grid squares of the computerized emissions grid networks. The distribution is illustrated on the grid map of Figure 5-9, and on the three-dimensional graphical emissions portrayal of Figure 5-10. It can be seen that dust from construction emissions is being generated further away from the downtown Phoenix area as development proceeds in future years. Comparison of the forecasted total dust emissions levels with the 1975 baseyear confirms the relatively low degree of construction activity in 1975.

Year	Dust Emissions from Construction tons/day
1975	100
1980	254
1985	256

5.2.7 Suspension of Dust from Paved Roads

Roadway improvements expected to be implemented over the next ten years will incur significant impact on street dust loadings. Due to a local roads improvement program in the city, the 200 existing miles of substandard city local streets will be upgraded by 1985. In addition, major streets will be renovated at the rate of about 20 miles per year.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S PHOENIX
MESA
GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .001
2	.001 to .005
3	.005 to .01
4	.01 to .04
5	.04 to .08
6	.08 to .15
7	.15 to .27
8	.27 to .43
9	.43 to .64

Figure 5-9. Grid Map for Total Dust Emissions from Construction Activities in 1985.

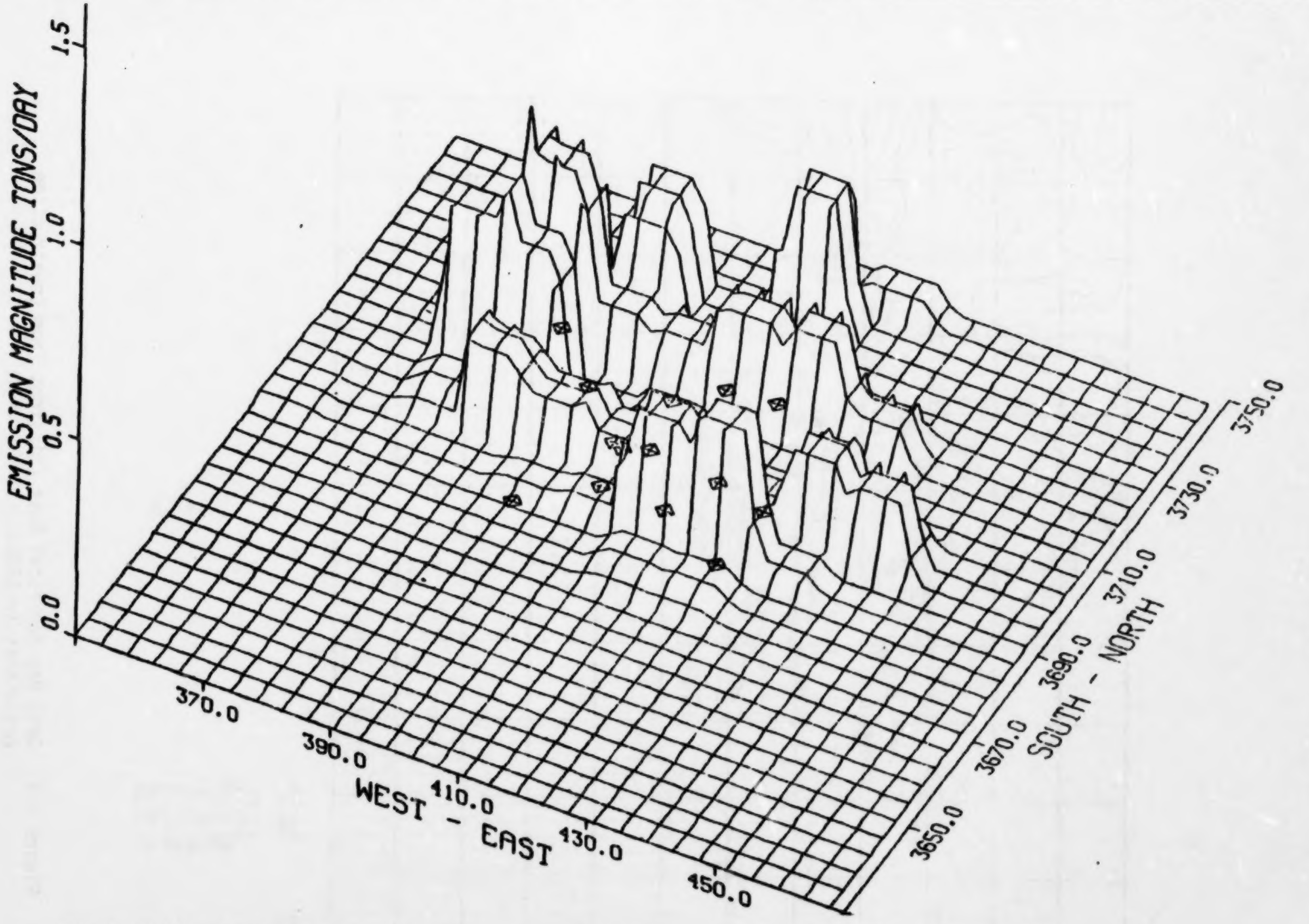


Figure 5-10. Forecast of Dust Emissions from Construction Activities, Daily Average, 1985.

Considering both local and major improvements, some 400 miles of city streets will be upgraded by 1985. Since there are some 120 miles of unpaved streets in the city at present, it may be reasonably assumed these will be paved by 1985. Further, it was assumed that the remaining 280 miles of street improvements was directed toward upgrading uncurbed streets. The impact of these improvements on total mileage of uncurbed streets in the city is shown below:

Road Type	Miles of Uncurbed City Streets 1975	 1980	 1985
Local	142	72	0
Collectors and Major	329	260	191

This data is important because dust loadings on streets with uncurbed road shoulders is four times less than that observed on curbed streets(see Section 3.7).

Most of the improvements in the county will consist of paving dirt or gravel roads. The county improvement program will probably exert only minor impact on the mileage of paved county roads currently unpaved.

Projections of dust emissions in 1980 and 1985 were based on population projections as discussed in Section 5.1. These projections were applied to the existing traffic network. The adjusted emission factor reflecting newly curbed streets was calculated by weighting the emission factors for uncurbed streets and curbed streets relative to the proportion of each of these street configurations in 1980 and 1985. The resulting emission factors for application to the baseyear transportation tape are:

Road Type in 1975	Dust Suspension Rate, g/vehicle mile 1975	 1980	 1985
Uncurbed Major and Collector	11.1	9.9	8.7

These emission rates are applied to the applicable streets in the city and unincorporated cities only, while emission rates remain unchanged for uncurbed roads in the county. At the same time, VMT changes in 1980 and 1985 cause associated increases in total dust suspension levels in both the city and county. The net effect of these changes on particulate emissions in the study area is summarized below:

Year	Suspension of Street Dust tons/day
1975	248
1980	295
1985	322

The gridded emissions inventory for suspended street dust in 1985 is shown in Figure 5-11. The distribution of these fugitive emissions is shown graphically in Figure 5-12 for 1985. Street dust emissions and seen to remain relatively unchanged in the city areas, but increase significantly in the county.

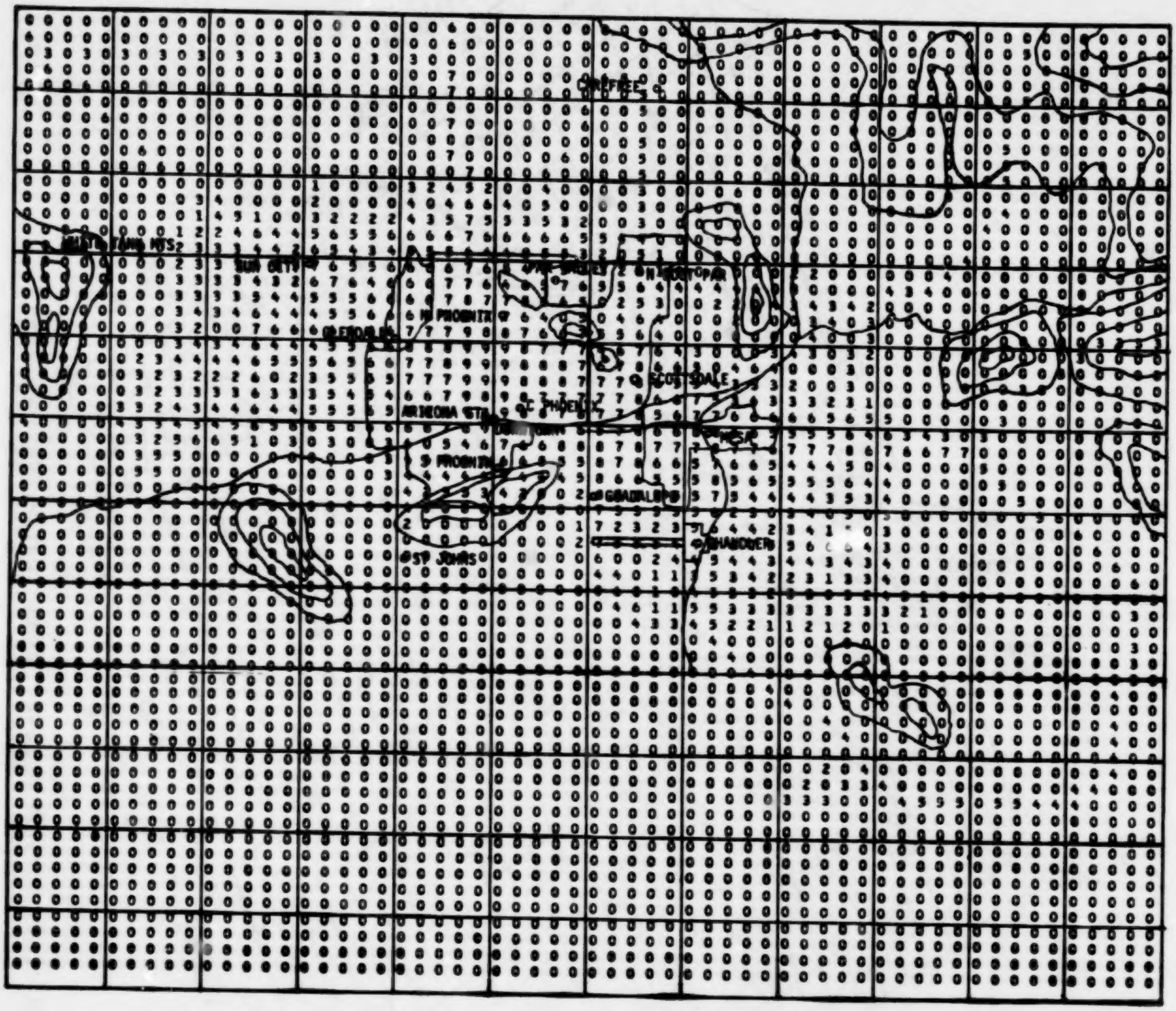
5.3 WINDBLOWN FUGITIVE DUST

This section documents the procedures employed to forecast dust emissions arising from wind blowing over various types of soil surfaces. The emissions forecasts are conducted for 1980 and 1985.

5.3.1 Unpaved Roads

The procedure for estimation of projected wind erosion emissions from unpaved roads is the same as that outlined in Section 4.2. The adjustments which must be applied to the baseyear parameters used in the wind erosion model concern: 1) the miles of unpaved roadways in the various grid sectors, and 2) the Climatic Factor. The former item is obtained by the considerations outlined in Section 5.2.1. The Climatic Factor, calculated to reflect typical annual and seasonal meteorology for the study area, is obtained from Table 4-4.

Forecasts of windblown dust off unpaved roads indicate substantial decreases from the baseyear levels. This is due mainly to the assertion that typical historical meteorology will prevail in the projected periods.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GUADALUPE
CHANDLER
ST JOHNS

GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .004
2	.004 to .02
3	.02 to .07
4	.07 to .18
5	.18 to .37
6	.37 to .69
7	.69 to 1.2
8	1.2 to 1.9
9	1.9 to 2.9

Figure 5-11. Grid Map for Dust Emissions off Paved Roads, 1985.

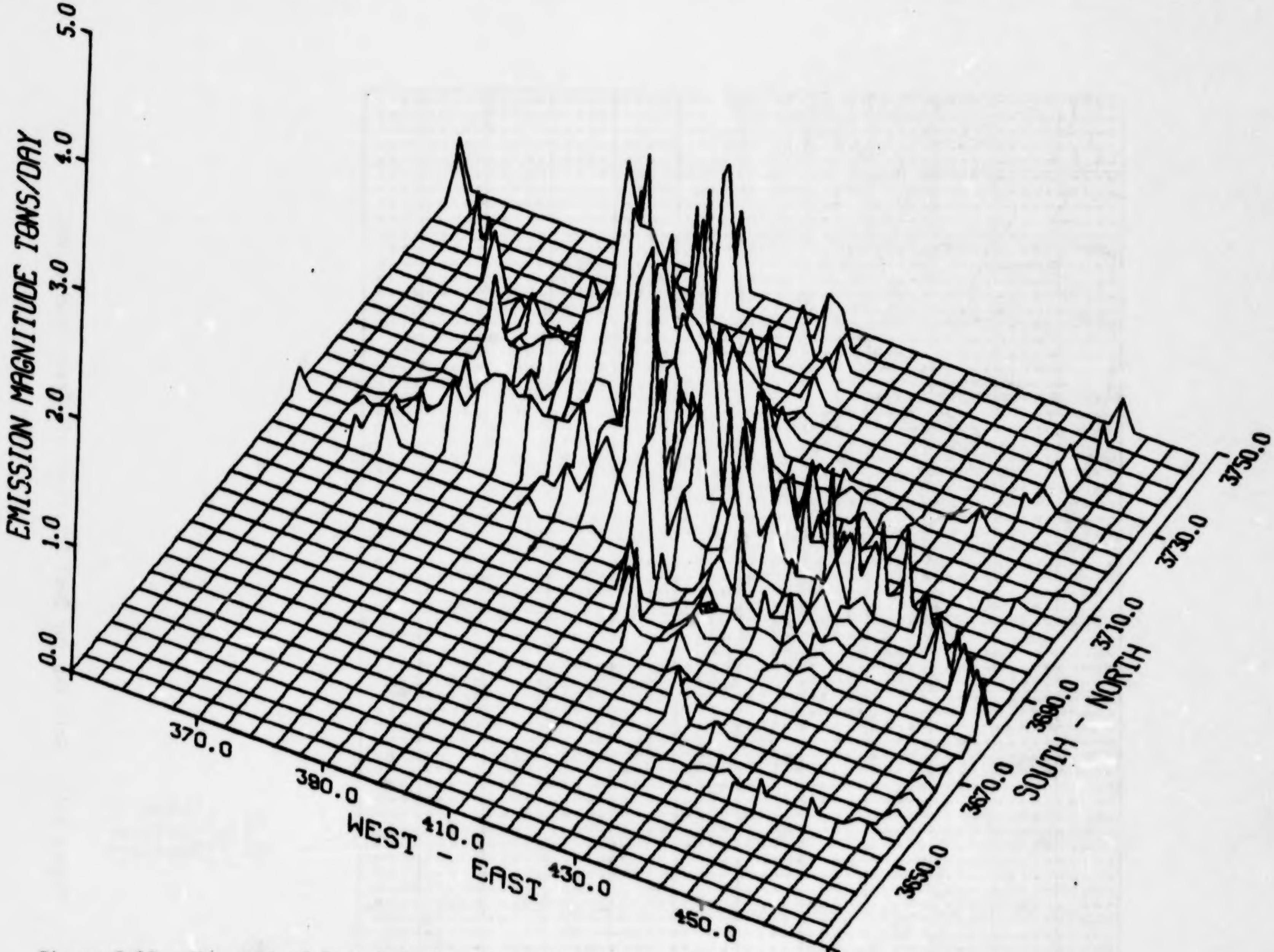

Figure 5-12. Forecast of Dust Emissions from Paved Roads, Daily Average, 1985.

QUARTER	TONS/DAY	
	1980	1985
1	.3	.3
2	.5	.5
3	.7	.7
4	.9	.9
Annual Average	.6	.6

5.3.2 Agricultural Fields

The procedure for estimating wind erosion emissions from agricultural fields in 1980 and 1985 is the same as that outlined in Section 4.3. The adjustments which must be applied to the baseyear estimates to obtain the forecasted emissions concern: 1) the amount of cropland acreage in each township, and 2) the anticipated Climatic Factor.

The location of cropland acreage was determined by evaluation of the general future land use map for Maricopa County[15] as described in Section 5.2.2. The total cropland acreage is not expected to change, however, location of croplands are expected to be displaced by urban expansion. Consequently, the spatial distribution of wind blown agricultural emissions will change, and the magnitude of emission levels will be affected slightly due to changes in soil errodibility. Distribution of crop acreage by crop type was assumed to remain constant in future years.

The most dramatic changes in windblown agricultural emissions levels are attributable to variations in climate. Assuming that historical climatic averages will prevail in future years, the crop-specific Climatic Factors for 1980 and 1985 are estimated to be approximately half of the value in the baseyear (when it was drier and more windy than normal).

The computational procedure of Section 4.3 was employed using the adjusted values of Climatic Factors and soil errodibility to obtain the emissions forecast summarized below.

QUARTER	TONS/DAY	
	1980	1985
1	1.7	1.7
2	1.7	1.7
3	1.6	1.6
4	1.7	1.7
Average	1.7	1.7

5.3.3 Undisturbed Desert

One consideration associated with projection of emissions from the desert surface involves changes in spatial distribution and total source area. Desert area is expected to diminish somewhat due to projected urban expansion. The total acreage of undisturbed desert in the study area was estimated by geometric plotting of the 1990 Future General Land Use Map [15]. The township by township acreage in 1980 and 1985 was derived by a linear interpolation of the diminishing acreage indicated between 1975 and 1990.

The major parameter involved in estimating future dust emissions from the desert is the Climatic Factor. Assuming that precipitation and wind speed for 1980 and 1985 will reflect historical averages for the study area, the Climatic Factors of Table 4-4 must be employed to derive the emission forecasts.

Based on the forecasted acreages of undisturbed desert land and Climatic Factors, emissions of dust off the desert pavement are estimated as shown below. The future emissions levels are estimated to be substantially less than were estimated in the baseyear. The reduction is attributable principally to the assumed change in climatology, as the change in total desert acreage is insignificant.

QUARTER	TONS/DAY		
	1975	1980	1985
1	160	66	66
2	244	112	112
3	321	104	104
4	450	56	56
Average	294	85	85

5.3.4 Tailings Piles

The change in quantities of windblown dust off tailings piles in future years was estimated by assuming that the size of the mineral waste heaps would grow in proportion to employment in the minerals industry. This expected growth in employment is 32% from 1975 to 1980, and 64% from 1975 to 1985 (see Section 5.1.2). The general location of the tailings piles is not expected to change. The emissions forecast for 1980 and 1985 is 1.9 and 2.3 tons/day, respectively.

5.3.5 Disturbed Soil Surfaces

Forecasts of windblown dust off vacant lots, unpaved parking lots and dirt residence yards were calculated by adjusting baseyear estimates to reflect changes in two parameters: the Climatic Factor, and the amount of disturbed soil surface. These parameters are directly related to windblown emissions levels.

The change in Climatic Factor from 1975 to future years is determined by assuming that the historical annual meteorology will prevail. The expected annual and seasonal meteorology has been calculated previously in Table 4-4.

Projection of the amount of vacant lands was based on the estimate that 15% of all potential urban area would be vacant in 1990, and that 50% of such potential urban area was vacant in 1973 [15]. This rate of decrease in vacant land was applied to the amount of vacant land inventoried for 1975 (see Section 4.6) to obtain the adjusted levels for 1980 and 1985.

The amount of exposed soil from dirt residence yards in the study area was assumed to increase in proportion to population growth through 1985. Accordingly, the increase from 1975 to 1980 is 27%, and from 1975 to 1980 the increase is 50%.

The spatial distribution of the disturbed soil surfaces was assumed unchanged. There was no legitimate basis for altering the distribution based on available information, and the assumption that vacant land inventoried in 1975 would diminish evenly throughout the study area, was considered plausible. Similarly, the assumption that the number of dirt residence yards would expand in the vicinity where they are now concentrated (economically depressed areas) seems plausible.

The future expected levels of windblown dust emissions from disturbed soil surfaces is summarized below. Changes in the levels are affected mostly by the assumption that "normal" meteorology will prevail in the future, as contrasted to the "unusual" climatological conditions in 1975 which favored high levels of windblown dust emissions.

QUARTER	TONS/DAY 1980	TONS/DAY 1985
1	85	43
2	151	77
3	138	70
4	77	39
Annual	114	58

REFERENCES FOR SECTION 5.0

1. Maricopa Association of Governments, "Maricopa County Projected Population Summary Page," Pamphlet with preliminary census projections, September, 1975.

2. Personal Communication, Wilma Richard of the Arizona Department of Economic Security, Labor Force Statistics Division, Phoenix, March, 1976.

3. Telephone Communication, Greg Witherspoon of the Maricopa County Department of Health, April, 1976.

4. U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors," Supplement No. 5, December 1975.

5. Arizona Department of Aeronautics, "State of Arizona Aviation Systems Plan, 1974-1993," December, 1973.

6. Wilbur Smith and Associates, L.H. Bell and Associates, "Highway Needs and Fiscal Study- Arizona's Future Highways," December 1967.

7. Arizona Department of Transportation, "First Biennial Statewide Transportation Needs Report to the Arizona Legislature," Phoenix, Arizona, January 1976.

8. Arizona Highway Department, Planning Survey Division, "Preliminary Report on Future Highway and Street Needs, Maricopa County, Arizona," Phoenix, Arizona, June 1970.

9. Arizona Highway Department, "Future Highway and Street Needs, Pinal County, Arizona," Phoenix, Arizona, May 1969.

10. Technical Advisory Committee, "Arizona Highway Studies," January 1968.

11. Maricopa County Highway Department, personal communication, March 1976.

12. Arizona Department of Transportation, Planning Survey Group, "Status of Road Systems Mileage," Phoenix, Arizona, 1972, 1973, 1974, 1975.

13. College of Agriculture, University of Arizona (Tucson), personal communication, April 1976.

14. Maricopa County Agricultural Agent, personal communication, April 1976.

15. Maricopa County Planning Department, "A Report Upon Future General Land Use for Maricopa County, Arizona," February 1975.

16. Arizona Department of Transportation, "Tentative Five Year Construction Program," 1976.

17. Arizona Highway Department, personal communication, April 1976.

18. City of Phoenix Traffic Department, personal communication, April 1976.

19. City of Phoenix, Arizona, "1975 Accelerated Major Street Program," July 1975.

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16. ABSTRACT

This document is one volume of a four volume report presenting an implementation plan for control of suspended particulate matter in the Phoenix area.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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